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(U.S.) Environmental Protection Agency
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Appendix D

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Waste Mangement Division
U.S. Environmental Protection Agency
401 M St. SW
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GUIDANCE CRITERIA FOR IDENTIFYING AREAS OF VULNERABLE HYDROGEOLOGY

APPENDIX D

DEVELOPMENT OF VULNERABILITY CRITERIA BASED ON RISK ASSESSMENTS AND THEORETICAL MODELING

Office of Solid Waste
Waste Management Division
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

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1.0 INTRODUCTION

This Appendix presents the results of the analyses that EPA performed in developing the definition of ground water vulnerability. In developing the vulnerability definition, EPA's primary goal was the identification of locations where the potential for exposure to releases of hazardous waste or waste constituents could be significant in the event of the failure or absence of engineered containment barriers or monitoring and response activities.

The Agency examined the effect on ground-water quality from a number of land-based hazardous waste management units located in a variety of hydrogeologic settings. This examination identified three generic potential pathways in the saturated zone through which the public or the environment could be adversely affected; these pathways are discussd in Section 2.0 of the main text of this guidance. EPA believes that results from these hydrogeologic assessments show that exposure potential is not minimized at locations where any of the three pathways exist. The vulnerability definition therefore must be able to identify these three pathways so that further steps can be taken to minimize potential exposure to human health and the environment in the event of a release.

Location vulnerability is determined for hazardous waste landfills, surface impoundments, and waste piles by calculating the time of travel of water along 100 feet of a ground-water flow line originating at the base of a hazardous waste management unit (TOT_{100}). For landfills and surface impoundments used for disposal, TOT_{100} values less than on the order of 100 years are considered to indicate vulnerable settings. For those land storage or treatment facilities where wastes will be definitely be removed at closure, the vulnerability of the ground water will be determined by comparing the TOT_{100} to the time that would be necessary to correct a problem in the event that design and operating controls in place at the facility failed. Determination of this time is site specific, and the permit writer should first ascertain that wastes and contaminated soils will be removed from the site at closure before considering a value for TOT_{100} that is less than on the order of 100 years.

The case studies and theoretical modeling analyses described in this Appendix discuss how the vulnerability definition can be used to recognize these pathways and thereby minimize potential exposure to the environment and human health by triggering further investigation of the location and reevaluation of design or operation considerations.

Chapter 2 of this Appendix describes the theoretical considrations affecting discharge and exposure potential, and how the concept of TOT_{100} incorporates these considerations. Using examples and plume modeling, it examines the relationship between TOT_{100} and contaminant discharge and travel through each of the three routes of exposure. The final section in Chapter 2 discusses overall site design and location strategy based on the objective of maximizing TOT_{100} and minimizing contaminant access to exposure pathways.

Chapter 3 of this Appendix presents illustrations of the three exposure pathways, and a health-risk and exposure estimation method for the the ground-water resource pathway. Ground-water quality data for actual or simulated ground water plumes were analysed to determine if any health risks might exist at a variety of hypothetical exposure points. Finally, case studies are included that illustrate the TOT$_{100}$ criteria and the health-risk assessment for the ground-water resource pathway.

Chapter 4 of this Appendix provides estimates on the number of facilities located in vulnerable settings.

2.0 THEORETICAL CONSIDERATIONS AFFECTING DISCHARGE AND EXPOSURE POTENTIAL

This chapter describes a series of exposure conditions that may result from ground-water contamination. The experience gained from investigations of CERCLA (Superfund) sites and the case studies described later in this Appendix has been used to identify and illustrate these exposure conditions.

Sections 2.0-1 through 2.0-3 examine the theoretical considerations affecting discharge of ground water and potential for exposure. The relationship between TOT and plume size is discussed, and an analysis of peak concentration in the plume versus TOT is described, using the Liner Location Model.

Section 2.1 discusses for the ground-water pathway the relationship between TOT and well yield and the TOT distribution among aquifers. The section contains a general discussion of the hydrogeologic settings where contamination can spread to high capacity production wells and individual drinking water wells.

Section 2.2 describes exposure potential through the second pathway, surface water contamination. Included are general examples illustrating the correlation between short TOT_{100} settings and the contamination of potable surface water supplies and surface water ecosystems, and the occurrence of contaminated seeps and springs.

Section 2.3 illustrates how exposure can occur through the basement seepage pathway. Section 2.4 discusses overall siting design and location strategies to minimize the potential for exposure through any of the three pathways.

Although the three pathways have been separately explained in this chapter, one must remember that they are closely linked in actuality. For example, contaminated ground water can discharge to surface water; leachate migrating along a shallow basement seepage pathway can discharge to drainage swales. Hence, the separation of the three pathways is a simplification to facilitate description and illustration of each route for the purposes of this appendix.

2.0.1 Relationship between TOT_{100} and the Potential Size of a Plume

The potential size of a plume is a function of the hydrogeologic characteristics of a location and the properties of the constituents released from the wastes. The potential rate of growth of a plume can be described by TOT_{100}.

TOT_{100} measured for water should describe the rate of growth of a plume unless constituents that move faster than water are present, such as when immiscible fluids are placed in the unit. However, EPA believes that these situations are atypical of most hazardous waste management units. When immiscible fluids are known to be present, their TOT_{100} can be easily calculated by converting the hydraulic conductivity (K) to a conductivity for the fluid of concern. This conversion requires a knowledge of the dynamic viscosity (μ, kg/m sec) and density (ρ, kg/m^3) of the fluid. The relationship is given by (Freeze and Cherry, 1979):

$$K = \frac{k \rho g}{\mu} \qquad (1)$$

where g is the acceleration due to gravity (m/sec^2) and k is the specific or intrinsic permeability (m^2), which is a function of the porous medium alone and which includes all the textural characteristics of the medium (i.e., mean grain diameter, grain size distribution, sorting coefficient, sphericity and roundness of grains, and the nature of their packing configuration). However, such a recalculation of TOT_{100} should not fundamentally change the interpretation of the plume isolation properties of the location, or of the potential for the hydrogeologic setting to be used as a ground-water resource. TOT_{100} calculated for water provides a simple means for comparing the natural containment characteristics of any hydrogeologic setting, thus providing a descriptive baseline for comparing the exposure potential at a facility. Where appropriate, the TOT_{100} for immiscible constituents can be calculated for the purpose of comparison.

The maximum potential extent of plume growth in ground water is described by the size of the ground-water flow cell, which is the distance between recharge and natural discharge zones. Flow cell characteristics can be related to geologic settings, and the dimensions can also be related to topographic position within the setting. In some settings, such as coastal plain deposits, the flow cell can be quite large, on the order of tens of miles or more. Other settings, such as low-permeability glacial till deposits with hummocky topography, have fairly short distances (on the order of hundreds of feet, depending on the topographic position). Table 2.0-1 lists the sizes of the flow systems at the sites studied in the Liner Location Project (which is discussed in more detail in Section 2.1.2). Freeze and Cherry (1979, Chapter 6) presents a more comprehensive discussion on flow systems.

Figure 2.0-1 shows that potential plume size is directly related to TOT_{100}. However, the maximum extent of a plume in ground water will be limited by any natural discharge zone. Except where such boundaries to the flow cell exist, the opportunity for exposure to a plume increases when TOT increases because the plume will underlie a greater area of land. Of course, when a plume's growth is limited by a natural discharge zone, the potential impact of the contaminated ground water on surface water quality must be considered.

2.0.2 Analysis of Peak Concentration as a Function of TOT_{100}

EPA examined whether there is a direct relationship between TOT_{100} and risk, to determine if waste disposal in certain hydrogeologic settings presents inherently less risk than in others. This analysis used peak concentrations as a proxy for risk because a common factor in all risk assessments is a comparison of constituent concentration data with toxicity guidelines for those constituents. The other factor in risk assessments is an evaluation of exposure potential; this factor is considered separately in the analyses presented in this Appendix.

The theoretical analysis of peak concentration versus TOT considers four contaminant release scenarios: continuous release at a constant release rate, continuous release at a rate determined by the ground-water flow velocity, constant rate contaminant release for a limited time period, and flow controlled contaminant

TABLE 2.0-1

HYDROGEOLOGIC DATA COLLECTED FROM LINER-LOCATION PROJECT LITERATURE SURVEY

Study Area	Unsaturated Zone		Saturated Zone		Flow Velocity (ft/day)				Flow System		Generic Setting	Source
	Earth Material	Layer Thickness (ft)	Earth Material	Layer Thickness (ft)	Min V_h	Min V_v	Max V_h	Max V_v	Distance From Rech. to Dischg. Boundaries[b] (ft)	Primary Mode of Discharge		
1-1	gravel	-[c]	gravel	25	25	-	110	-	21,000	river	1	Konizeski et al. (1968)
			silt, clay	300	-	0.006	-	-		aquifer		
			sand, gravel	>400	0.01	-	0.04	-	40,000	river		
1-2	gravel, sand	-	gravel, sand, silt	0-3000	2.8	-	6.3	-	-	river	5	Dion (1969)
			basalt	400-1000	65	-	-	-	-	river		
2-1	alluvium	10-20	alluvium	30-40	4.5	-	-	-	-	river	1	Price (1962)
2-2	gravel, sand	50-100	gravel, sand, silt	150	0.35	-	2.10	-	42,000	river	1	Londquist (1981)
			clay	60	-	3.6×10^{-6}	-	6×10^{-6}	-	aquifer		
			gravel, sand, silt	600	0.70	-	2.10	-	-			
2-3	gravel, sand silt	50-100	gravel, sand, silt	300	1.7	-	5.0	-	21,000	wells	1	Hardt et. al (1980)
			clay, silt	200	-	2	-	6	-	aquifer		
			sandstone	>400	0.9	-	1.8	-	-	aquifer		
2-4	clay, silt sand, gravel	100-250	clay, silt sand, gravel	>200	0.63	-	1.6	-	27,000	well	1	Anderson (1972)
2,3-1	-	-	sand, gravel	30-60	0.21	-	-	-	-	river	1	Bertoldi (1973)
3-1	sand, gravel	20-200	sand, gravel;	200	67	-	220	-	32,000	lake	7	Tanaka et al. (1974)
			clay, silt	100	-	4[d]	-	10[d]	32,000	aquifer		
			basalt	>100	0.08	-	0.21	-	32,000	aquifer		
3-2	sand, gravel	200	silt, sand	>1200	0.38	-	0.64	-	53,000	wells	1	Newcomb et al. (1972)
3-3	-	-	sediment, basalt	5000	5	-	25	-	-	-	1	Barraclough, et al. (1976) Robertson, et al. (1974)
4-1	sandstone	0-300	sandstone	0-700	0.11	-	0.22	-	21,000	spring	1	Lundy (1978)
			faulted sandstone	>100	5.6	-	12.0	-	-	-		
4-2	-	-	sandy clay	0-135	0.025	-	-	-	-	wells	6	Raymondi, et al. (1983)
			sandstone	70	0.43	-	-	-	-	wells		
5-1	sandstone	20-80	sandstone	>300	0.09	-	0.60	-	-	wells	1	Lowry et al. (1967)

continued

TABLE 2.0-1 (continued)

	Unsaturated Zone		Saturated Zone						Flow System			
					Flow Velocity							
					Min		Max					
Stuly Area	Earth Material	Layer Thickness (ft)	Earth Material	Layer Thickness (ft)	V_h	V_v^a (ft/day)	V_h	V_v	Distance From Rech. to Dischg. Boundaries[b] (ft)	Primary Mode of Discharge	Generic Settting	Source
5-2	sandstone	50-100	sandstone	150	0.27	-	3.0	-	21,000	stream	1	Hudson (1965)
6-1	limestone	0-500	limestone	550	0.04	-	0.4	-	53,000	aquifer	1	Konikow (1976)
6-2	sand, silt, gravel	10	sandstone	20	-	-	-	-	3,000	stream	1	Davis (1975)
	sandstone	20-50	coal	70	0.61	-	3.0	-	-			
6-3	sand, silt, gravel	-	sand, silt, gravel	15	0.80	-	5.3	-	6,000	river	1	Konikow (1976)
6-4	sandstone	50-200	sandstone	300	0.20	-	0.40	-	16,000	well	1	Trauger et al. (1964)
6-5	-	6-10	limestone	50	0.49	-	-	-	-	spring	1	Turk et al. (1971)
6-6	fractured limestone	0-200 -	fractured limestone	600	0.13	-	0.24	-	-	spring	1	Klempt et al. (1979)
6-7	limestone	-	sandstone	100	0.04	-	0.16	-	-	aquifer	7	Hall et al. (1975)
			shale, limestone	50	-	$2x10^{-5d}$	-	$2x10^{-4d}$		aquifer		
			sandstone	100	0.06	-	0.26	-		aquifer		
6-8	-	-	karstic limestone	-	26	-	-	-	5,000	stream	1	Harvey et al. (1968)
6-9	-	-	karstic dolomite	-	1.9	-	2.6	-	-	-	1	Skelton et al. (1979)
6-10	karstic limestone	-	karstic limestone	>1,000	24	-	180	-	-	spring	1	Harvey (1980)
6-11	shale	-	shale, siltstone	40	-	0.002^d	-	0.003^d	-	aquifer	3	Zehner (1983)
			sandstone	40	0.03	-	0.26	-	-	spring		
			shale	>300	-	0.008^d	-	0.01^d	-	aquifer		
7-1	sand, gravel	10	sand, gravel	150	0.02	-	0.05	-	53,000	spring	1	Baker et al. (1967)
			granite	-	-	-	-	-	-	-		
7-2	-	-	sand, gravel, silt	-	1	-	3	-	-	-	1	Otton (1972)
7-3	sand, gravel	-	sand, gravel	90	0.64	-	1.3	-	10,000	river	1	Rothrock et al. (1947)

continued

TABLE 2.0-1 (continued)

Study Area	Unsaturated Zone		Saturated Zone						Flow System		Generic Settting	Source
	Earth Material	Layer Thickness (ft)	Earth Material	Layer Thickness (ft)	Flow Velocity (ft/day) Min V_h	Min V_v^a	Max V_h	Max V_v^a	Distance From Rech. to Dischg. Boundaries[b] (ft)	Primary Mode of Discharge		
7-4	till, sand	8	till, sand	>1000	-	-	-	-	-	aquifer	3	Kent et,al. (1972)
			shale	200	-	-	-	-	-			
			limestone	25-260	0.025	-	0.58	-	-	-		
7-5	-	-	sand, gravel	90	3.4	-	-	-	16,000	river	1	Kaymick et al. (1981)
7-6	-	-	sand	75-130	1.5	-	1	-	130,000	river	1	Rothschild et al. (1982)
7-7	sand, gravel	-	sand, gravel	50	-	-	-	-	-	-	1	Zeizel et al.
			dolomite	200	0.21	-	0.43	-	-	wells		
7-8	-	-	sand, gravel		0.04	-	0.27	-	-	-	1	Otton (1972)
7-9	silt	-	clay, silt	50	0.15	-	1.8	-	600	stream	1	Gibb (1978)
7-10	-	-	sand, gravel	-	1	-	-	-	-	-	1	Otton (1972)
7-11	silt, clay		sand, gravel	40	1.3	-	4.8	-	-	river	1	Planert (1980)
			silt, clay	60	1	$8x10^{-5}$	-	$6x10^{-4}$	-	aquifer		
			sand, gravel	50	1.4	-	4.8	-	-	-		
			limestone	100	-	-	-	-	-	-		
7-12	sand, gravel	10	sand, gravel	30	0.01	-	0.10	-	-	creek	2	Pettijohn (1977)
			silt, clay	100	-	0.001	-	0.002	-	aquifer		
			sand, gravel	20	0.8	-	1.6	-	-	underflow		
7-13	sand, gravel, silt	10	sandstone	74	18	-	51	-	16,000	river	1	Matisoff et al. (1982)
			clay till	20-217	-	-	-	-	-			
7-14	till	10-20	till	30	0.0055	-	-	-	5,200	river	3	Maslia et al. (1982)
			dolomite	15	0.055	-	-	-	5,200	river		
			dolomite	60	0.03	-	-	-	5,200	river		
			shale	>50	$1x10^{-5}$	-	-	-	4,200	river		
8-1	saprolite	3-17	saprolite	0-50	0.023	-	0.043	-	-	streams	2	Maryland DLP (1981)
8-2	gneiss (weathered)	-	gneiss (weathered)	100	0.56	-	3.1	-	5,000	stream	1	McGreevy and Sloto (1980)
9-1	silt, clay	10	silt, clay	100	0.002	-	0.01	-	10,500	river	1	Trainer et al. (1962)
			dolomite	>100	0.17	-	0.69	-	10,500			

continued

TABLE 2.0-1 (continued)

	Unsaturated Zone		Saturated Zone						Flow System			
					Flow Velocity							
					Min		Max					
Study Area	Earth Material	Layer Thickness (ft)	Earth Material	Layer Thickness (ft)	V_h (ft/day)	V_v^a (ft/day)	V_h (ft/day)	V_v^a (ft/day)	Distance From Rech. to Dischg. Boundaries^b (ft)	Primary Mode of Discharge	Generic Settting	Source
9-2	sand, gravel		sand, gravel	35	1.9	-	6.2	-	-	creek	1	Gushue et al. (1981)
9-3	sand, gravel	10	sand, silt, clay crystalline rock	80 >500	2.4 -	- -	14 -	- -	3,200 -	river aquifer	1	Harni (1978)
9-4	sand, silt, clay	-	sand, silt, clay basalt	200 >500	0.36 -	- -	3.0 -	- -	2,000 -	river -	1	LaSala (1968)
10-1	-	-	sand	1000	0.006	-	0.29	-	-	-	1	Pearson et al. (1967)
10-2	sand	150	sand	>400	0.28	-	0.47	-	-	stream	1	Alexander et al. (1966)
10-3	sand	-	sand, gravel	>1000	0.05	-	0.2	-	-	wells	1	Wood et al. (1965)
10-4	clay, sand	10-30	clay, sand sand sand silty clay	20 100 150 75	0.042 0.02 0.02 -	- - - -	8.4 4.3 0.2 -	- - - -	3,000 3,000 3,000 -	springs springs creek -	5	Cahill (1982)
10-5	-	-	limestone	100	0.58	-	-	-	52,000	creek	1	McCollum et al. (1964)
10-6	-	-	limestone	>1000	0.018	-	0.018	-	-	ocean	1	Hanshaw et al. (1965)
10-7	-	-	sand, clay	23	0.0035	-	0.008	-	-		2	Hutchinson et al. (1978)
10-8	-	-	sandstone, limestone	100	1.8	-	3.5	-	-	well	1	[illegible] (1960)
10-9	sand	-	sand clay	100 30	0.53 -	- -	1.1 -	- -	- -	wells	1	North Carolina D.N.R. (1978)
10-10	sand, gravel	30	sand, gravel clay sand, gravel crystalline rock	200 200 100 >100	0.24 - 0.10 -	- $1x10^{-5}$ - -	0.64 - 0.26 -	- $6x10^{-4}$ - -	 - - -	wells aquifer aquifer	7	Mack (1962)

continued

TABLE 2.0-1

Study Area	Unsaturated Zone		Saturated Zone						Flow System		Generic Setting	Source
					Flow Velocity (ft/day)							
					Min		Max					
	Earth Material	Layer Thickness (ft)	Earth Material	Layer Thickness (ft)	V_h	V_v^a	V_h	V_v	Distance From Rech. to Dischg. Boundaries[b] (ft)	Primary Mode of Discharge		
10-11	-	-	sandstone	80	0.84	-	-	-	-		1	Boedecker et al. (1979) DeWalle et al. (1981)
10-12	sand, gravel	10-20	sand, gravel	200	0.03	-	0.10	-	42,000	well	1	Luzier (1980)
			schist	>100								
10-13	sand, gravel	10-100	sand, gravel	90	0.16	-	0.72	-	53,000	stream	1	Getzen (1972)
			clay	20	-	1×10^{-4}	-	5×10^{-4}	-	aquifer		
			sand, gravel	200	0.04	-	0.19	-	-	well		
10-14	sand, silt, clay	90	sand	10	1.3	-	2.1	-	-	stream	1	Sprinkle (1978)
			silty clay	100	-	-	-	-	-	-		
11-1	sand, gravel	-	sand, gravel	150	0.64	-	1.3	-	10,000	river	1	Croft (1973)
			sandstone	>200	-	-	-	-	-	-		
11-2	sand, gravel	-	sand, gravel	100	0.32	-	0.64	-	-	-	1	Dalsin (1978)
11-3	sand, gravel	-	sand, gravel	30	0.22	-	0.45	-	2,000	river	8	Marie (1975)
			fine sand	100	-	0.04[d]	-	1.2[d]	100	aquifer		
			sand, gravel	30	1.3	-	2.2	-	-	river		
			shale	>50	-	-	-	-	-	-		
11-4	sand, gravel	-	sand, gravel	100	0.45	-	3.0	-	13,000	river	1	Planert et al. (1979)
			limestone	-	-	-	-	-	-	-		
11-5	-	-	sand, gravel	-	5	-	-	-	-	river	1	Grubb (1970)
11-6	sand, gravel	-	sand, gravel	100	0.45	-	3.0	-	5,000	well	1	Walton et al. (1960)
			shale	>200	-	-	-	-	-			
11-7	sand, silt, clay	-	sand, silt, clay	75	27	-	55	-	15,000	river	1	Wilmoth (1966)
11-8	sand, gravel	-	sand, gravel	200	27	-	80	-	-	wells	1	Winslow et al.
			shale, schist	>500	-	-	-	-	-	-		

---

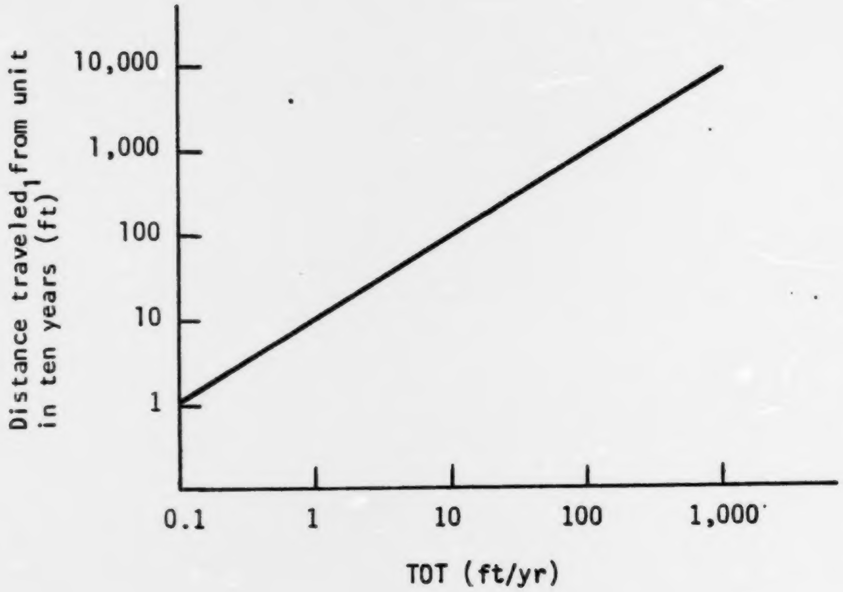
[a] Vertical groundwater flow is upward unless otherwise indicated

[b] Maximum horizontal distance from recharge to discharge groundwater divides

[c] A dash indicates that information was not reported

[d] Downward groundwater flow

FIGURE 2.0-1 POTENTIAL AREAL EXTENT OF A PLUME AS A FUNCTION OF TOT PER UNIT TIME



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[1] The distance traveled in ground water will be limited by the dimension of the flow cell in a given geologic setting. The figure shows the potential areal extent when plume growth is not limited by natural discharge zones.

release for a limited time period. The first of these scenarios shows increasing steady state concentrations with increasing TOT, the second and third show peak or steady state concentrations to be unrelated to TOT and the fourth shows decreasing peak concentrations with increasing TOT.

Steady State

If the release of a contaminant into an aquifer for a finite period of time is assumed to occur at a point, then the following equation describes the variation of contaminant concentration with time and distance along the direction of the flow:

$$C(x,t) = \int_0^t \frac{Q(t') \exp\left(\frac{-(x-V(t-t'))^2}{4D_x(t-t')}\right)}{8\, n_e \sqrt{\pi^3 (t-t')^3 D_x D_y D_z}}\, dt' \quad (2)^*$$

where

$C(x)$ = Concentration (grams/meter^3) distance x (meters);

$Q(t')$ = Time dependent contaminant release rate (grams/second) to the aquifer at point $x = 0$;

V = Seepage velocity for the aquifer (meters/year);

D_x = Dispersion in the direction of flow (meters^2/year);

D_y = Dispersion in the horizontal direction perpendicular to the direction of flow (meters^2/year);

D_z = Dispersion in the vertical direction (meters^2/year); and,

n_e = Effective porosity ($0 < n_e \leq 1$);

---

*Equation (2) is modified by GCA Corporation from Freeze and Cherry (1979) equation 9.6 (on page 395) for the case $y = z = 0$.

This equation describes the effects of hydrodynamic dispersion. It does not consider the effects of contaminant degradation or sorption to soil particles.

For a release rate Q_o, which does not vary with time, the steady state concentration ($t \rightarrow \infty$) is given by:

$$C(x,\infty) = \frac{Q_o}{4\pi x n_e \sqrt{D_y D_z}} \qquad (3)^{**}$$

In the analysis, the following assumption/definitions are also made:

$C_{max}(x)$ = Maximum concentration at distance x considering all values of $C(x,t)$

Time of Travel (TOT) = $\frac{x}{V}$

$D_x = \alpha_L V$

$D_y = \alpha_T V$

$D_z = \alpha_T V$

The values α_L and α_T are the longitudinal and transverse dispersivities, respectively. Both α_L and α_T have units of meters. The contaminant release rate, Q_o, used in Equation (3) can be written as follows:

$$Q_o = jV \qquad (4)$$

where

j = either a constant or a variable (units of g/m) depending on whether or not the release rate, Q_o, is flow dependent.

** Equation (3) is from Hunt (1978).

Equation (3) can then be written as:

$$C(x,\infty) = \frac{jV}{4\pi x\, n_e V\sqrt{\alpha_T \alpha_L}} \qquad (5)$$

$$= \frac{j}{4\pi x\, n_e\sqrt{\alpha_T \alpha_L}}$$

If the release rate is constant with respect to velocity, then the source term Q_o is constant and j is inversely proportional to V. In this case, as TOT increases, j increases and the peak concentration increases. With constant contaminant release, the steady state concentration at distance x is higher for longer TOT.

If the release rate is flow-controlled (proportional to the flow velocity within the aquifer), then Q_o is proportional to V, and j is constant. In this case, the steady state concentration at distance x is independent of velocity and, therefore, TOT.

Releases Over a Limited Time Period

Some releases may only last for a period T_r. In this case, the time dependent release rate Q(t') used in Equation (2) is given by:

$$Q(t') = jV \quad \text{for } 0<t'<T_r \qquad (6)$$

$$= 0 \quad \text{for } t'>T_r$$

For a constant release rate Q_o over a finite period T_r, the term jV will be constant and the peak concentration $C_{max}(x)$ at a distance x will be independent of the TOT.

For flow-controlled releases having a finite period, the peak concentration, $C_{max}(x)$, at a distance x will actually decrease with increasing TOT. The amount of this decrease will depend upon the period of release and the distance from the source. This relationship is illustrated in Figure 2.0-2, which shows the ratio of maximum to steady state concentration for different values of TOT and release period. In this example, the distance x has been chosen as 30 meters and the longitudinal and traverse dispersivities, α_L and α_T, have both been set equal to 0.1 meter. Changing the dispersivities and treating the release as an area source will change the profiles shown in Figure 2.0-2 but will not change the overall inverse relationship which has been established between TOT and peak concentration.

2.0.3 Application of the Liner Location Model

As discussed in Section 2.0.2, peak concentration of contaminants within a plume (and therefore, risk) is a function of TOT_{100}; this section illustrates this relationship in a variety of hypothetical hydrogeologic settings.

The use of specific case studies to determine potential health risk and exposure potential across a range of hydrogeologic settings, as described in Section 3, is a complex task that can be limited by inaccurate site characterization data. However, the advantage of this method is that it offers a site-specific presentation of the distribution of contamination resulting from releases from a unit, along with an assessment of the quality of the contaminated ground water.

An alternative or supplement to the use of case studies is the use of a model by which a variety of hypothetical site conditions can be examined. This approach is similarly complex but lacks the "real world" sense of the case study method. It does, however, provide a powerful means by which specific aspects of a

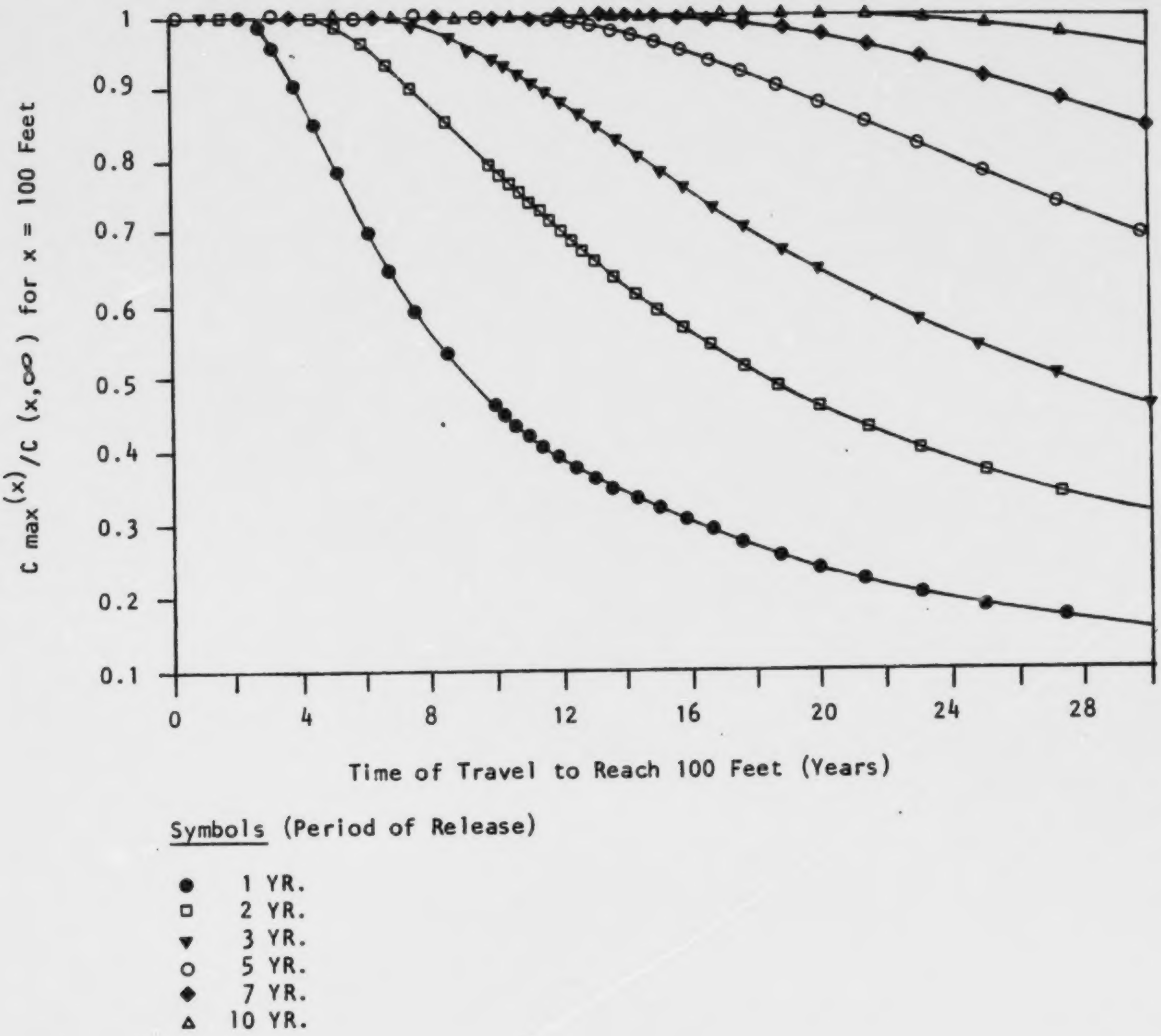


FIGURE 2.0-2 Ratio of Peak to Steady State Concentration as a Function of Time of Travel (TOT) and Period of Release at a Distance of 100 Feet from the Release Point ($\alpha_T = \alpha_L = 0.1$)

problem can be isolated for examination by holding other aspects constant.

Modeling also provides an opportunity to examine the effects of hazardous waste management in hydrogeologic settings with long TOTs. The steady-state characteristics of plumes in these settings cannot be thoroughly examined using case studies, simply because insufficient time has passed since facility operations began in those settings for a plume to mature to such dimensions. Modeling provides a method for estimating when such dimensions might be reached, and what the characteristics of such a plume and its relationship to an uppermost aquifer might be.

The model selected for this work is the Liner Location Model developed by EPA to assess the contaminant concentrations and health risks associated with a range of TOT_{100} conditions (as well as other characteristics) at hypothetical sites. The model has a number of subroutines, including ones for ground-water flow and solute transport. The version of the model used in this analysis was not designed for site-specific use; EPA is refining the model and plans to make it adaptable for site-specific use.

Results of Model Use

This effort examined six generic, vertically-oriented ground-water flow fields covering a range of ground-water flow velocities from 100 feet in 10 years to 100 feet in 1,000 years. Peak concentrations were determined for a point 100 feet along the ground-water flow line from the source. The hydrologic subroutine is described in Attachment 1.

Different scenarios were generated for each setting by varying key parameters, as follows:

- Two contaminant mobilities were examined. These were class 1, retardation factor of 1.3, and class 2, retardation factor of 32.
- Two source loading mechanisms were examined: equal mass input and flow field controlled mass input. Equal mass inputs could be controlled by either the facility design/failure mode or an underlying unsaturated zone. Flow field controlled inputs are masses released at a rate determined by the flow field which continue for a fixed time period. The total mass released varies with flow field velocity.

The principal results of the hydrologic model are summarized in Table 2.0-2, which shows peak contaminant concentrations and 100-foot travel time for the six generic settings. Variations are shown for the two chemical mobility classes and for the two source loading assumptions. For the hydrogeologic settings considered, there is no clear relationship between peak concentrations produced by instantaneous equal mass releases at the source and velocity or TOT_{100}. This is consistent with the discussion in Section 2.0.2 which showed these variables to be independent. Variations in concentration shown in Table 2.0-2 are due to variations in other variables such as porosity and the influence of multilayer velocities in scenarios M, N, and O. Where time-limited mass releases are controlled by the flow field (including diffusion-controlled transport with high velocity contrasts), peak concentrations decrease with increasing TOT_{100}.

TABLE 2.0-2 CRITICAL TIMES AND PEAK CONCENTRATIONS AND 100-FOOT TRAVEL TIMES FOR TWELVE SCENARIOS

	Critical times			Peak concentrations		Time of travel to 100 ft.
Scenario identification	Start (yr)	End (yr)	Peak time (yr)	Standard load[a] (mg/l)	Adjusted load[b] (mg/l)	(yr)
J-1-100	300	5,000	1,250	42.4	3.9	1,000
J-2-100	8,000	110,000	32,270	1.80	.17	1,000
K-1-100	35	450	115	19.5	35.	100
K-2-100	800	11,000	3,000	.92	1.7	100
L-1-100	4	53	12	20.5	370.	10
L-2-100	80	1,100	320	.87	16.	10
M-1-100	250	120,000	1,360	1.2	.054	1,083
M-2-100	8,000	360,000	33,000	.048	.0022	1,083
N-1-100	120	800	260	14.7	4.8	186
N-2-100	3,000	20,000	6,440	.63	.21	186
O-1-100	5	120	21.5	9.9	65.	18.6
O-2-100	150	3,500	550	.45	2.9	18.6

[a] Standard mass load of one kilogram for one year over the strip source area (32.8 ft^2).

[b] Standard mass load adjusted by flow field-controlled leachate release rates.

The difference in relationships between peak concentration and velocity/TOT_{100} highlights the importance of the source term in the model. This modeling study also shows that the lowest concentrations are associated with settings that include very low velocity surficial layers with diffusion-controlled transport overlying an aquifer that would otherwise have received higher inputs of contaminants and would not have met the current TOT_{100} criterion.

Conclusions of Preliminary Use of Liner Location Model

This preliminary analysis supports the use of the TOT_{100} criterion where source removal or corrective action can limit the duration of the contaminant releases. In this circumstance, the magnitude or mass loading of the release is controlled by the low-velocity flow field.

This analysis also shows that zero concentration cannot be achieved for nondegrading constituents as long as a waste source exists. Contaminants will move, albeit slowly and in minimal volume, through low-velocity flow fields. These constituents can eventually reach aquifers and, hence, points of potential exposure. However, as shown in Table 2.0-2, these times may be far into the future, on the order of thousands of years. This result further supports the view that the TOT_{100} criterion describes settings that minimize the potential for exposure to releases.

2.1 POTENTIAL FOR EXPOSURE THROUGH A GROUND WATER RESOURCE

The potential for exposure to contamination through a ground water resource can be described by two main factors. The first factor relates to the plume character, which includes its potential size and the peak concentration of contaminants, as discussed in Section 2.0. The second factor in potential exposure is related to the probability that the saturated zone could supply a sufficient volume of water for residential use or other purposes. As described in this section, the vulnerability criterion, TOT_{100}, provides a measure for potential exposure because it incorporates a consideration of these factors.

2.1.1 Theoretical Relationship between TOT_{100} and Well Yield

This section discusses the theoretical relationship between TOT_{100} of ground water within a saturated zone and the potential yield (Q) of a discharging well in the same zone.

Time of Travel

The technical analysis examined well-documented mathematical expressions, commonly used by hydrogeologists to analyze travel time and well yield.

The general expression for calculating TOT in a homogeneous, isotropic media through which ground water is flowing under the influence of a uniform hydraulic gradient is:

$$TOT = \frac{Ln_e}{Ki} \qquad (7)$$

where TOT = time of travel, (T)

L = length of flow path, (L)

n_e = effective porosity, (dimensionless)

K = hydraulic conductivity, (L/T)

i = hydraulic gradient, (dimensionless).

Equation (7) is used in the definition of ground-water vulnerability when L is set equal to 100 feet. It shows that TOT is inversely proportional to both hydraulic conductivity and hydraulic gradient. A long TOT can be associated with very low permeability materials, very low hydraulic gradient, or both.

Well Yield

The steady radial flow to a discharging well in a confined aquifer is described by (Thiem, 1906):

$$Q = 2\pi Kb \frac{h - hw}{\ln (r/rw)} \qquad (8)$$

where Q = constant well yield, (L^3/T)
K = hydraulic conductivity, (L/T)
b = constant aquifer thickness, (L)
h = hydraulic head at radial distance r, (L)
hw = hydraulic head at the well, (L)
r = radial distance associated with h, (L)
rw = radius of the well, (L)

A more general form of the equation can be obtained by letting $r = r1$, $rw = r2$, while $h = h1$ and $hw = h2$. Equation (8) can then be rearranged to obtain an expression for the hydraulic conductivity (Todd, 1959, page 83):

$$K = \frac{Q \ln (r_2/r_1)}{2\pi b\,(h_2-h_1)} \qquad (9)$$

Consideration of the equations for TOT and well yield can be taken further by substituting Equation (9) for K in Equation (7). This yields the following expression:

$$TOT = \frac{2\pi L\, n\, b\,(h_2-h_1)}{Q \ln (r_2/r_1) i} \qquad (10)$$

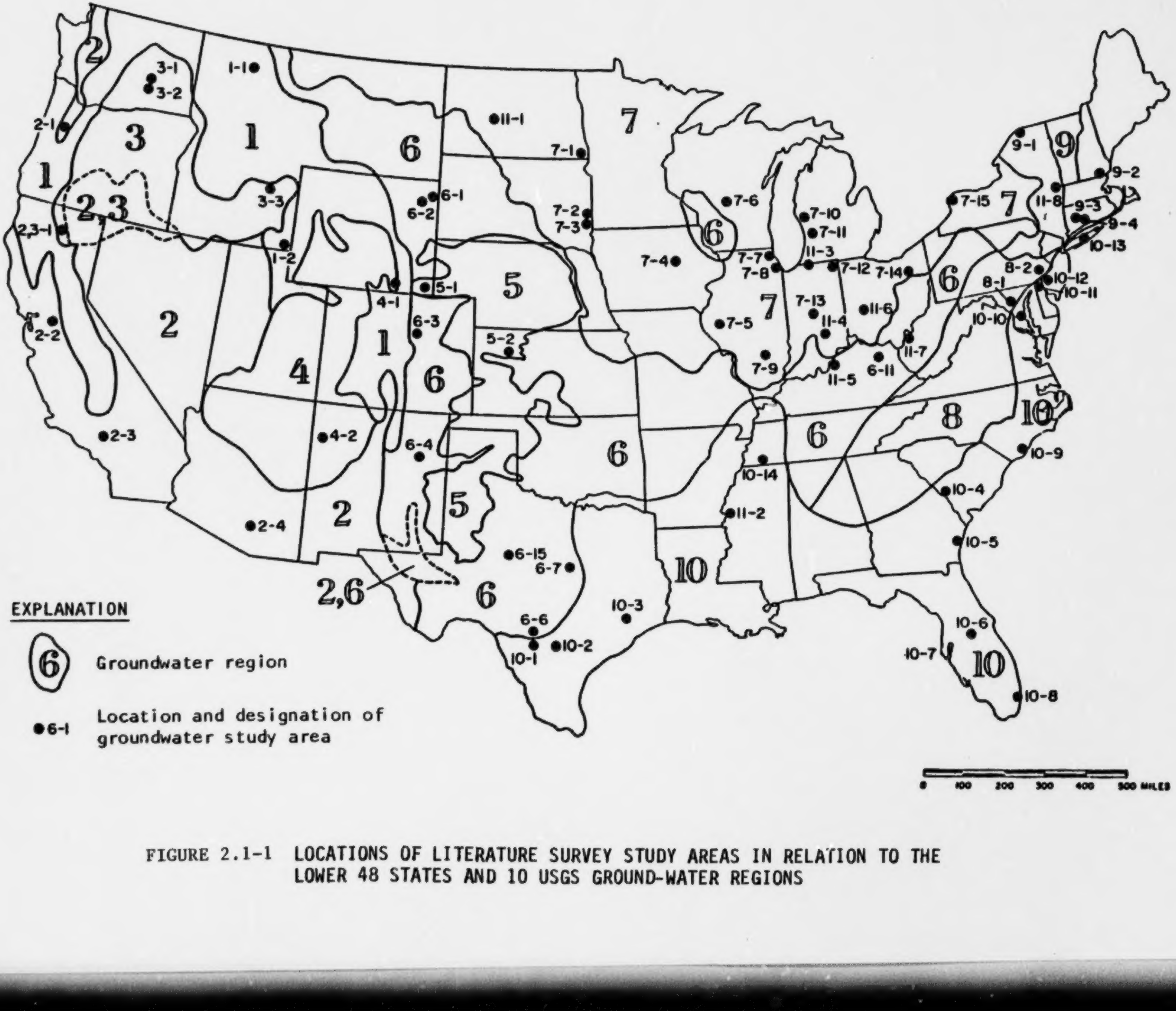
Both well yield and TOT are sensitive to hydraulic conductivity. A very low conductivity regime will tend to have both long TOT and low well yields. Facilities located in such "non-aquifers" (i.e., aquitards) should have a minimal potential for exposing human and environmental resources to contaminants released to ground water because the chances for aquifer exploitation are minimal.

However, the relationship between yield and TOT is also influenced by porosity, well drawdown, aquifer thickness and hydraulic gradient. A setting with a high hydraulic conductivity and a very low hydraulic gradient can have both long TOT and high potential well yields. This occurrence illustrates the importance of considering changes in hydraulic gradient due to aquifer exploitation in evaluating TOT, as discussed in Section 3.2.2 of the main text of this guidance.

2.1.2 Frequency Distribution of TOT Among Well-studied Aquifers

This section summarizes information on 67 case studies of existing hazardous waste land treatment, storage, and disposal facilities reviewed during Phase I of the Liner Location Project for the Office of Solid Waste (EPA, 1983). The location of the 67 facilities is shown in Figure 2.1-1.

Figure 2.1-2 is a histogram that presents the frequency of occurrence of horizontal ground-water velocities collected in the survey. Table 2.0-1 summarizes the basic data for each case study. Because the majority of cases represented well-studied aquifers that were also well developed for water supply, the velocities may be biased toward the high end of the range of


EXPLANATION
6 Groundwater region
●6-1 Location and designation of groundwater study area
1-1
1-2
2-1
2-2
2-3
2-4
2,3-1
3-1
3-2
3-3
4-1
4-2
5-1
5-2
6-1
6-2
6-3
6-4
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6-7
6-11
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11-3
11-4
11-5
11-6
11-7
11-8
1
2
3
4
5
6
7
8
9
10
2,3
2,6
0 100 200 300 400 500 MILES

FIGURE 2.1-1 LOCATIONS OF LITERATURE SURVEY STUDY AREAS IN RELATION TO THE LOWER 48 STATES AND 10 USGS GROUND-WATER REGIONS

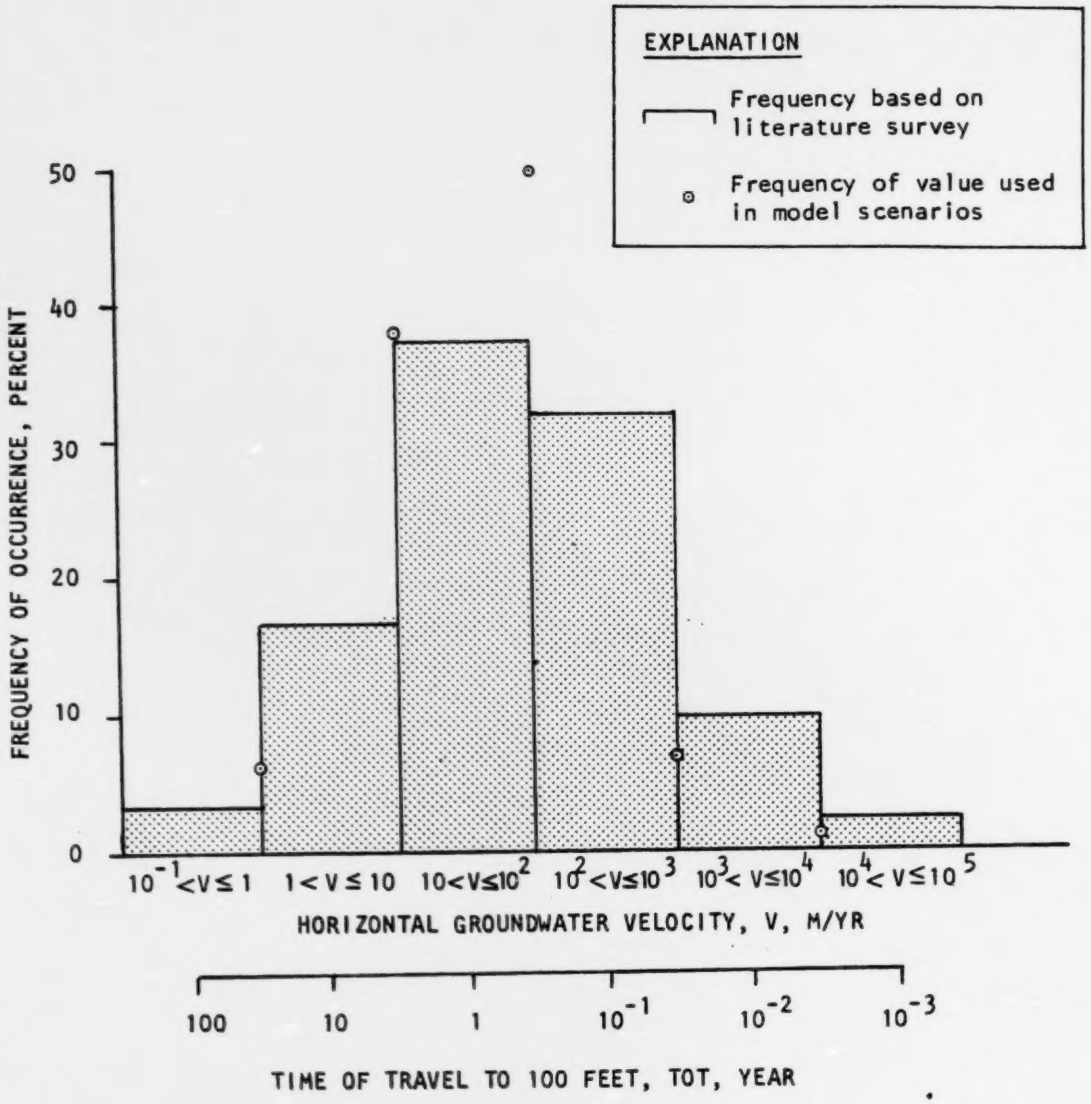


FIGURE 2.1-2 Histogram of Ground-water Velocities Generated in Literature Survey in the Liner-Location Project

possible velocities. In addition, some, but not most, case studies represent confined aquifers, not the uppermost aquifer. Consequently, there is some question about how representative this data-base is of conditions underlying RCRA facilities.

A TOT_{100} scale is shown at the bottom of Figure 2.1-2 in order to show the relationship of the criteria to the aquifer-oriented database. Clearly, TOT_{100} values on the order of 100 years occur infrequently among the 67 case studies (about 4%).

This information suggests important conclusions: TOT_{100} values on the order of 100 years or more are uncharacteristic of aquifers, and facilities located in nonvulnerable settings are unlikely to discharge to geologic formations that supply a significant quantity of water for sustained uses.

2.1.3 Contamination of High Capacity Production Wells

A common condition resulting in risk and exposure occurs when contaminated ground water is intercepted by high capacity production wells. The public is at risk when municipal wells are contaminated, while the potential for worker exposure exists when industrial wells are threatened by contamination. If irrigation wells become contaminated, the irrigated crops may also take up the contaminants, which can result in contamination of the entire food chain.

The conditions described above are most likely to occur in areas with high-yield aquifers in which high-production wells are likely to be located. In general, these aquifers consist of thick deposits of unconsolidated sands and gravels, or other highly porous media, such as fractured or poorly cemented sedimentary rocks, or fractured limestones. Often, the well fields are situated near streams and rivers, where induced recharge from surface waters supplements the available ground-water supply. The TOT_{100} in these types of hydrogeologic settings is always very short because such productive aquifers are highly permeable.

Because continuous pumping of significant quantities of water at these well fields can alter the pre-existing flow paths and even create reversals in the direction of ground-water flow, sources of contamination may be very difficult to identify. Pumping may also shorten TOT_{100} if it has been calculated under natural conditions, because the cone of depression around such wells will increase the hydraulic gradient, which is also directly proportional to velocity.

2.1.4 Contamination of Individual Drinking Water Wells

Contamination of domestic water supplies is becoming increasingly more common. In 1970, nearly 20 percent of the United States population relied on individual wells for drinking water and domestic use. In rural areas, many contaminated domestic wells have had to be abandoned due to releases from hazardous waste management facilities.

Individual drinking wells can be located in many kinds of hydrogeologic settings because even aquifers with very small yields (as low as half a gallon per minute) can provide sufficient quantities of water for domestic use. The geologic settings range from fractured crystalline bedrock to highly permeable sand and gravel deposits. TOT_{100} is highly variable because of the wide range of hydrogeologic settings. Well depths range from only a few feet to over a thousand feet, although the majority of wells are between 100 and 300 feet deep. In general, domestic wells located in unconsolidated materials are shallow, depending on the depth to the water table. These wells are the most susceptible to ground-water contamination because most hazardous waste facilities are located at or near the surface; hence, contaminants will often be most concentrated near the top of the aquifer. Exceptions would include contamination from underground injection wells that dispose of wastes to deeper portions of the aquifer, and contamination by constituents that are much denser than water.

2.2 POTENTIAL FOR EXPOSURE TO CONTAMINATED SURFACE WATER

The theoretical discussions of ground water contamination presented in Sections 2.0 and 2.1 also relate to the second pathway of exposure, surface water contamination, because contaminated ground water can discharge to surface water bodies through springs, seeps, and baseflow.

This section describes conditions and representative hydrogeologic settings that can lead to contamination of surface water.

2.2.1 Surface Water Exposure Pathway: Hydrogeologic Settings

Surface waters and ground waters are interdependent components of the hydrologic cycle; a change in one of these components may have a significant impact on the other. Contamination may be transported from ground water to surface water in discharge areas, which occur in topographic lows. These situations arise when the net saturated flow of ground water is toward the water table, which is often at or very near to the ground surface.

If the discharge rate is low or flow occurs over a large area, diffuse seepage may occur, moistening the ground. However, seepage along streams or lake banks may produce a volume sufficient to provide a main source of stream flow during dry periods (baseflow).

Surface water bodies may also receive ground water from springs. Springs arise when a discharge from an aquifer is concentrated in a small area, and they commonly occur in areas of fractured bedrock or karst topography.

Discharge of ground water is related to precipitation and will vary seasonally with the amount of water that is stored in the saturated zone and, therefore, with the slope of the potentiometric surface. Nested piezometers may be installed to determine if an area has an upward component of flow characteristic of a discharge area.

2.2.2 Contamination of Potable Surface Water Supplies

An example of a situation that presents a risk to human health is the contamination of surface water bodies, such as lakes, reservoirs, ponds, or rivers, that serve as drinking water supplies. A risk can also exist if creeks, streams, rivers, or their tributaries that eventually empty into a drinking supply are contaminated. Surface water may become contaminated by direct discharge of contaminants from a point source to the water body or by contaminated runoff. Contaminated ground water may also be a source of surface water contamination if it discharges to the surface water body.

2.2.3 Contamination of Surface Water Ecosystems

When a body of surface water becomes contaminated, it poses a risk to aquatic organisms or the entire ecosystem that it hosts. Humans are also at risk if they have contact with the contaminated water through recreational activities or if they ingest aquatic life, such as fish, that dwell in the water. Animals may also be exposed if they drink the water or ingest any aquatic organisms.

2.2.4 Bedrock Springs Contamination

In some cases, the identification of contaminated ground water is first made in areas where springs are visibly contaminated. Indications of contaminated springs or seeps include noxious odors, dead or dying vegetation or animals near the springs, and the presence of oil. The presence of a contaminated spring is usually a strong indication of a much larger problem.

In general, springs and seeps occur where the water table intersects the surface. Several types of springs can occur, depending on the hydrogeologic setting. A depression spring is likely to occur in a topographic low spot, thereby creating a local discharge zone. Contact springs are likely to occur at the contact between a high permeability layer and an underlying low permeability layer. Faulting can create a similar condition when a low permeability layer is juxtaposed with a high permeability layer. In areas underlain by limestone, springs are very common because of the creation of solution features, such as caverns and sinkholes. Springs are also common in areas with fractured, low permeability rock. Water movement occurs along the joints and fractures, and spring water discharges where the fractures intersect the surface.

Given otherwise similar hydrogeologic settings, the TOT_{100}

will nearly always be shorter where springs and seeps are present than where they are absent. Springs and seeps often reflect the presence of pathways of low resistance, such as solution channels in limestones or joints in crystalline rocks, along which ground water tends to flow. Abandoned mine shafts create a similar condition, in which rapid transport of contaminants occurs in water-filled shafts.

2.3 POTENTIAL FOR EXPOSURE THROUGH THE BASEMENT SEEPAGE PATHWAY

2.3.1 Description of Condition

Exposure can occur when contaminants enter basements of homes and buildings through ground-water seepage or vapor phase transport of methane and other toxic gases. To anyone living in the area, this condition poses a serious threat through exposure to toxic chemicals and fumes and through the potential for fires and explosions resulting from highly combustible gases.

2.3.2 Representative Hydrogeologic Settings

This condition can occur in a variety of hydrogeologic settings. However, the risk from contaminants seeping into basements is most likely to be present in areas where the water table is permanently or seasonally above the level of the basement floor or where an upper isolated saturated zone exists. Vapor phase transport is a more serious problem in settings where there are interconnected pathways between the contaminated aquifer and the surface, such as fractured bedrock or porous unconsolidated sand and gravel deposits. The presence of noxious odors is often the first indication of a problem.

TOT_{100} varies in settings where basement seepage occurs.

The pathways themselves may be localized features with short TOT_{100} values that provide the path of least resistance for contaminant transport in a predominantly long TOT_{100} setting. For instance, such pathways may consist of sand lenses, permeable topsoil, or man-made conduits such as buried utility lines or gravel-filled drainage swales.

When a facility is underlain predominantly by a low permeability layer (where TOT_{100} is long), increased recharge, both artificial and natural, could cause ground-water mounding. This elevation of the water table may create the opportunity for contaminants to travel through previously inaccessible pathways (the 'bathtub effect'), unless that pathway is already accessible due to a high water table. One must also examine the potential impact of artificial containment barriers installed to lengthen TOT_{100}, or the failure or stripping off of a cover, in causing a bathtub effect (see Section 3.1 for examples of contaminant transport through the basement seepage pathway). The potential for this pathway to exist may be recognized by examining flow patterns that would result from the greatest hydraulic head that could occur at a unit. Section 3.2.2 of the main text discusses how these heads can be determined. If the pathway could exist, modifications in unit design might prevent migration, as discussed in the next section.

2.4 CONSIDERATIONS FOR LOCATION AND UNIT DESIGN

The optimum nonvulnerable setting for a hazardous waste management unit is one that minimizes the potential for exposure to human health or the environment by limiting waste migration potential through each of the three pathways: exposure to a contaminated ground water resource, exposure to surface water contaminated by discharging ground water, and exposure through the "basement seepage" (near-surface flow) pathway. The vulnerability definition is an important trigger for evaluating overall site performance under several major design scenarios.

2.4.1 Controlling Discharge from a Unit

The hydrogeologic characteristics of a location can control the amount of fluid released to the saturated zone from a landfill, surface impoundment, or waste pile, thereby helping to control a plume at its source. An effective design evaluation includes an assessment of how natural controls can be used to minimize fluid discharge, in addition to engineered components such as liners and caps.

The volume of fluid discharged across an area within the saturated zone per unit time (Q) can be calculated as:

$$Q = -KiA, \qquad (11)$$

where Q = flow (L^3/T)
K = hydraulic conductivity (L/T)
i = hydraulic gradient
A = cross-sectional area of flow (L^2).

Because $Q \propto K$ and $Q \propto i$, settings with low hydraulic gradients and low hydraulic conductivities (i.e., long TOT_{100} values) can minimize discharge from the waste management unit depending upon whether the discharge is controlled by the flow field. This can best be understood by considering the potential performance differences of a unit in the unsaturated and saturated zones.

Unsaturated Zone

The potential discharge from the facility located wholly above the water table equals the amount of infiltration passing through the cover (or direct precipitation, if no cover is present) and the bottom liner (if any), plus the volume of any run-on and fluids present within the unit. If the liner and the cover are truly impermeable, there should be no discharge. If this condition is not satisfied, the discharge will be as high as the infiltration through the cover, or the fluid volume placed within the unit plus incident precipitation and run-on during unit operation. Consequently, prevention or minimization of discharge requires both advanced design considerations and long-term, active unit maintenance.

When a discharge occurs from a unit in the unsaturated zone, the hydraulic gradient along the flow path from the unit to the ground-water table will be high (close to 1.0). If the discharge is substantial, a ground-water mound might be created beneath the unit; mounding can increase the pre-existing hydraulic gradient within the saturated zone as well, with a consequent increase in Q and reduction of TOT_{100}.

The relationship between TOT_{100} and peak concentration (or risk) for such cases is discussed in Section 2.0.2 under the descriptions for the constant release scenario, in which peak concentration increases with increasing TOT_{100} for a continuous release. A release occurring over a limited time period displays a peak concentration unrelated to TOT_{100}.

Saturated Zone

This discussion applies only to below-grade units, in which the maximum elevation of waste placement is below the top of the saturated zone. At closure, the final cover would fill the excavation to the original grade.

At a facility where waste is located entirely within the saturated zone, the potential discharge through the liner (if any), can be limited to the natural flux of ground water passing across the boundary of the unit. The discharge would be greater only when the hydraulic gradient is increased by either fluid addition during operation (assuming no impermeable liner) or infiltration through the cover in excess of pre-existing conditions. In addition, the seepage velocity of ground water would be equal to pre-site velocity unless the gradient is increased.

This situation corresponds to the flow field controlled scenarios described in Section 2.0.2, in which peak concentrations (and hence, risk) are reduced as TOT_{100} increases. The success of a unit located entirely within a low-permeability saturated zone primarily depends on the ability of the final cover to limit infiltration to levels that are not significantly greater than those prior to unit construction; failure of the cover to perform properly could allow mounding and migration along the third pathway.

2.4.2 Considerations for Unit Design

Limiting access to the three exposure pathways is critical for optimal unit design. One design scenario for a unit in a low-permeability nonvulnerable setting would be to:

- review the impact of passive flow barriers that may be installed,
- keep wastes well below grade to prevent formation of the basement seepage pathway or leachate springs (see Figure 2.4-1), and
- maintain the integrity of the cover so that excess infiltration does not create a bathtub effect.

This design scenario optimizes the use of passive methods to minimize the potential for exposure to releases that occur due to human oversight and the failure or absence of man-made barriers. It highlights the other major option for minimizing exposure potential, which is to provide long-term (perpetual) monitoring and response. For example, if such active controls were ensured through an institutionalized oversight and response program, hydrogeologic setting would be less critical in long-term exposure minimization.

2.4.3 Considerations for Storage and Disposal Units

Unit design and location considerations can be affected by whether a unit is operated and closed as a storage unit or as a disposal unit.

Storage Units

Because wastes are removed from storage units at closure, a release from a storage unit can occur only during a limited period of time. Because the owner or operator is responsible for ground-water monitoring and corrective action during this period (the active period of the storage unit), any release that occurs should be detected and corrected as necessary, in response to the permitting standards of 40 CFR 264 Subpart F. As discussed

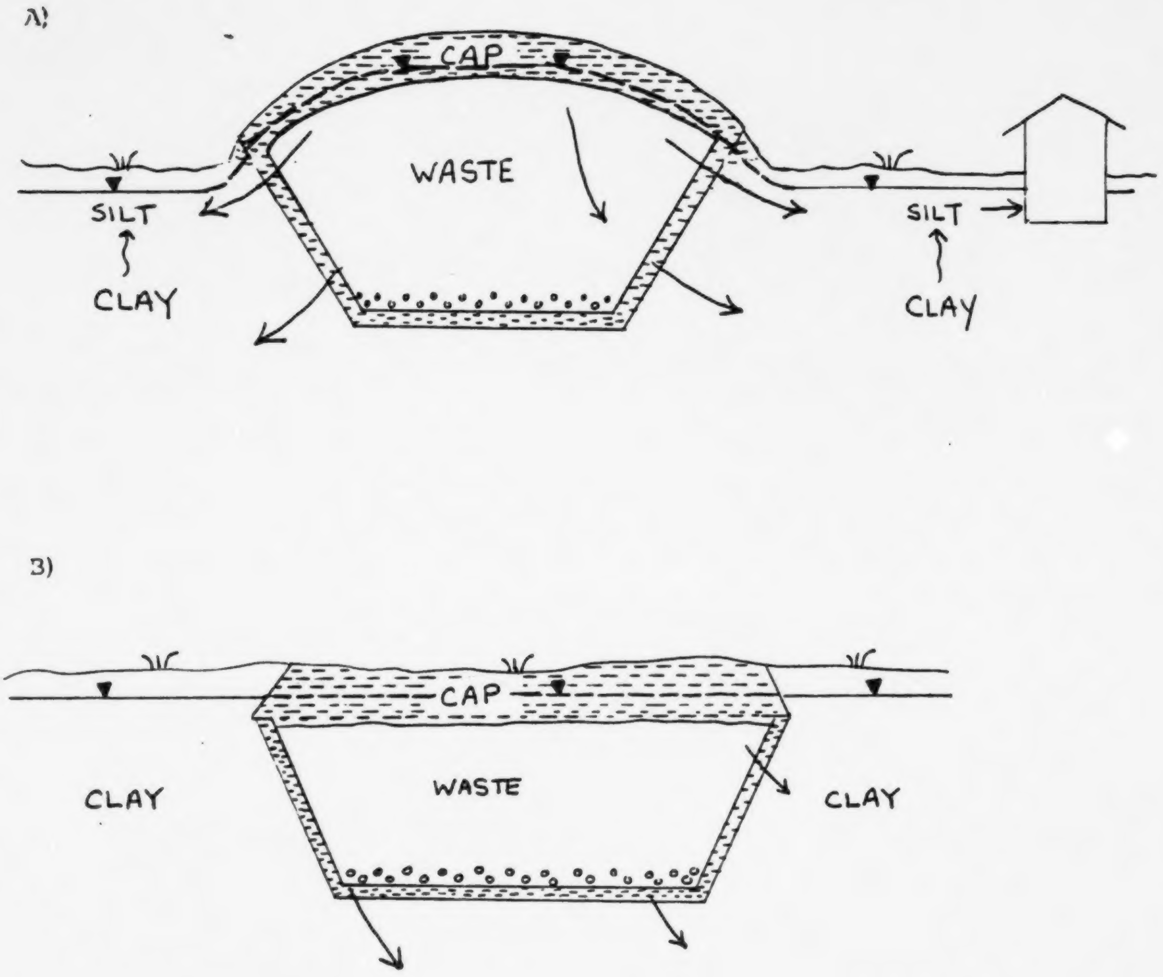

A)
CAP
WASTE
SILT
CLAY
SILT
CLAY
B)
CAP
WASTE
CLAY
CLAY

FIGURE 2.4-1 Schematic illustrations of unit design. Figure A shows waste disposed above grade. The high hydraulic head causes flow along the near surface silty layer as well as vertically into the clay. Figure B shows the optimal unit design, with wastes deposited below grade, with a thick cap filling the excavation, thus inhibiting access through the basement seepage pathway.

in Section 2.0.2, such limited time releases can occur under either a constant release or a flow-controlled release scenario. A constant release scenario, typical of a unit placed in the unsaturated zone, yields a peak concentration that is unrelated to TOT_{100}. A storage unit located in an unsaturated zone should not pose a risk of exposure if the setting provides an adequate time period for plume detection and implementation of corrective action.

A storage unit placed in the saturated zone would be characterized by a flow-controlled release, in which peak concentration decreases as TOT_{100} increases. While the long TOT_{100}-saturated zone setting may be more protective in the event of a release, the major location consideration is to provide adequate time for plume detection and response. In fact, a longer TOT_{100} setting may impede the efficiency of a corrective action, owing to increased sorption capacity of fine-grained sediments and the decreased ability of collection wells to capture and remove the plume rapidly.

Disposal Units

Because wastes are not removed from disposal units at closure, the potential exists for continuous and long-term release of contaminants to the environment. A disposal unit could have either a flow-controlled continuous release, or a constant continuous release.

As discussed in Section 2.4.2, a leaking disposal facility located in an unsaturated zone would correspond to a constant release scenario; the magnitude of the constant rate of flow from the unit depends on the degree of failure of the unit design, is complicated by ground-water mounding, and thus is generally unpredictable.

Releases occurring from disposal units located in the saturated zone may be controlled by the natural ground-water flow velocities. Although the peak concentration in flow-controlled releases is unrelated to TOT_{100}, the size of the plume is limited in a long TOT_{100} setting (Section 2.0.1), and discharges from the unit would be minimal and predictable (Section 2.1.1). Thus, a long TOT_{100} setting is especially important for disposal facilities where the absence of long term care necessitates a setting that minimizes the potential for exposure to future releases. Isolation of wastes completely within saturated, low-permeability materials offers this potential.

3.0 CASE STUDY EXAMPLES AND EXPOSURE ESTIMATION METHODS

This chapter uses case studies to illustrate exposure and health risk estimates for each exposure pathway in a variety of hydrogeologic settings. The case studies show that exposure to ground-water contamination is most frequently documented at locations with hydrogeologic settings exhibiting short TOT_{100}. The vast majority of ground-water contaminant plumes and their ultimate threat to human health and the environment have resulted from hazardous waste disposal in locations where ground-water flow is rapid and contaminants may be transported to a well, spring, or surface water body. In hydrogeologic settings with predominantly long TOT_{100} values, observed health threats have resulted from the failure to recognize and prevent seepage of contaminated ground water and associated toxic vapors along near-surface, short TOT_{100} pathways into basements and subsurface utilities.

However, evidence of contamination in short TOT_{100} settings is expected because many existing hazardous waste sites located in settings with long TOT_{100} values would not be expected to have ground water contaminated to the point where a problem would have been detected. Conversely, sites exhibiting short TOT_{100} values would develop ground-water plumes rapidly as a result of improper or ill-considered waste disposal activities and consequently are much more likely to cause detectable contamination that subsequently would be investigated.

Because plume detection may be biased towards short TOT_{100} settings, and because of the occurrence of basement seepage pathways, long TOT_{100} settings should not be considered automatically safe for siting. The examples presented in this section suggest strongly that regional hydrogeologic settings and related land and water uses surrounding the hazardous waste management facility site should be evaluated thoroughly during the facility permitting process.

The brief case descriptions in Section 3.1 illustrate the relationship between TOT_{100} and the three exposure pathways. Exposure and risk through the potential pathways are discussed for each case in qualitative terms, because sufficient data were not readily available for quantitative risk assessments. An exception is the example in Section 3.1.7 for which more quantitative information was available for the third pathway analysis.

As an example of the type of health risk methodology that can be applied to a specific pathway, Section 3.2 discusses assessment methods that can evaluate the potential health threat to humans exposed to contamination through potable ground water.

Finally, case studies illustrating the application of this health risk assessment for ingestion of contaminated drinking water are presented in Section 3.3; other pathways are indicated when present.

3.1 CASE STUDIES: THREE EXPOSURE PATHWAYS

These case studies are general summaries designed to illustrate the relationship between TOT_{100} and all three exposure pathways. No rigorous health assessment methodology has been used for these case studies.

3.1.1 Ground-Water Resource Pathway: Chemical Plant Site

Description of Condition

A large chemical plant was operated at the site until 1982. Nearby residents have filed complaints about odors and irritants in the air since 1973. The town drilled five highly productive wells in the area, but odors in the water from these wells indicated the presence of contaminants. Local and state authorities conducted a more detailed investigation of the company's disposal practices in 1978 after the company submitted a proposal for expansion at the site. The investigation resulted in the shutdown of two town wells as a precautionary measure, which reduced the town's drinking water supply by 40%. The company has agreed to clean up the contaminated areas and restore the quality of the aquifer supplying the town wells.

Hydrogeologic Setting

The site occupies about 500 acres and is underlain by unconsolidated sands and gravels deposited near the end of the Wisonsin Glaciation. These deposits have been extensively mined, especially in the southern portion of the property. The plant and associated landfill are located on the northern part of the property.

The stratified glacial deposits range in thickness from a few tens of feet to about 120 feet. A thin discontinuous layer of till separates the sands and gravels from the underlying metamorphic gneiss bedrock. The ground water in the gneiss occurs primarily in the joints and fractures in the uppermost portion of the formation. The hydrogeologic investigation of the site showed that there is a hydraulic connection between the ground water in the bedrock and the overlying aquifer.

Based on existing hydraulic conductivity data, an average hydraulic gradient of .004, and an effective porosity of 20 percent, velocities were determined to range from 3 ft/day (sand and gravel) to .2 ft/day (silty fine sand). Therefore, the shortest TOT_{100} would be about 33 days and the longest would be 500 days.

In addition to the very short TOT_{100}, the original flow paths have been altered significantly by interference from multiple pumping wells in the area. Furthermore, the ground water flow paths are subject to change, depending on the rates of recharge and pumping. This variation makes a reasonable long term prediction of contaminant migration very difficult in this type of setting.

3.1.2 Ground-Water Resource Pathway: Abandoned Gravel Pit/Landfill

Description of Condition

This site in the northeastern U. S. includes two landfills located in an abandoned gravel pit on a lake shore. Both municipal and industrial wastes, including chemical wastes, were disposed of for nearly 50 years. Twenty-one homes adjacent to the landfill were obtaining drinking water from private wells when the contamination was discovered in 1979. In 1980, volatile organic compounds were detected in a residential well south of the site. The lake and the domestic wells are seriously threatened by the landfills.

Hydrogeologic Setting

The site is located in unconsolidated sand and gravel deposits where TOT_{100} values would be expected to be short, underlain by an irregular bedrock surface. A deep bedrock trough containing as much as 150 feet of glacial and marine sediments underlies the northeastern part of the site. The general direction of ground-water flow is eastward toward the lake; however, local flow patterns are much more complex and vary temporally with fluctuations in rainfall and the lake level.

3.1.3 Potable Surface Water: Multi-Source Waste Site

Description of Condition

The site area, located within a valley, provides an example of a long-term, multi-source contamination problem. Seepage from industrial and municipal waste impoundments is the major source of ground-water contamination. However, leaking sewers and storage tanks, use of sewage sludge as fertilizer, and spills of contaminated fluids in commercial and industrial areas have added to the problem. The ground water flows toward the east and discharges to a shallow narrow stream that drains into a major reservoir on the river that supplies about half of the total water used in the valley. Elevated concentrations of total dissolved solids are present in ground water and surface water sampled in the stream and its tributaries. The dissolved solids consist of high concentrations of iron, chromium, lead, lithium, strontium and zinc. A plume of nitrate-rich ground water extends to the stream from a large industrial park, 3 to 4 miles downgradient from the site. The continued movement of contaminated water poses a potential threat to the water quality of the lake.

Hydrogeologic Setting

The site area lies within a bedrock valley that is partly filled with unconsolidated deposits consisting of beds and lenses of sand, silt, gravel, and clay up to several thousand feet thick. The bedrock valley is comprised of relatively impermeable igneous and sedimentary rocks.

The unconsolidated deposits form several major hydrogeologic units at the site. The uppermost aquifer is composed of sand and gravel; the water table within this aquifer ranges from land surface near the stream, to as much as 50 feet below land surface elsewhere in the valley. Underlying this uppermost aquifer is a confining unit composed of silt, clay, and fine sand; several artesian aquifers are interfingered with these confining beds. Regional ground-water flow is from the recharge areas along the bordering highlands to the discharge areas in the lowlands, where water from both the shallow and underlying deep aquifers seeps into the stream. TOT_{100} for this setting is estimated to be short through the unconsolidated sands and gravels of the uppermost aquifer.

3.1.4 Surface Water Ecosystems: Mining and Ore Processing Facility

Description of Condition

An abandoned mining and ore processing facility produced titanium dioxide for paint pigments between 1931 and 1971. During its period of operation, the facility either disposed of acidic wastes in sedimentation ponds or discharged these wastes, untreated, into a nearby river. Between 1977 and 1980, four major fish kills occurred in the river; the State has attributed these fish kills to the facility. Although the acidic waste liquids are no longer present in the evaporation ponds, ground water and soils still exhibit acidic conditions. Residual sludges and other materials are buried on the site; some unreacted ore and ferrous sulfate is located within the soil in evaporation ponds or scattered at the surface.

Surface water runoff from the site exhibits low pH values (acidity) and high metals concentrations; ground-water sampling has also revealed low pH values, elevated metals concentrations, and sulfate contamination. Human exposure from the facility is considered to be low, given the remote location of the site. The nearest drinking well is located to the north upgradient of the site; when tested, the water did not contain metals or other contaminants above ambient background levels. The closest drinking water source downstream of the river is 40 miles away.

The two environments at risk of exposure are terrestrial flora and fauna around the clay-lined iron sulfate pit and the aquatic ecosystem of the river. The primary routes of exposure to these receptors are ground-water discharge and surface water runoff. The forest areas located in the path of ground-water flow and surface runoff, and benthic flora and fauna in the river downstream of the site, face the highest risk. Water having certain low pH values has been shown to be acutely toxic to aquatic species.

Hydrogeologic Setting

The facility lies in the foothills of the Blue Ridge Mountains along a river; and occupies approximately 510 acres. The facility is set on a hillside within the river drainage basin. Soils are composed of clay and silty clay. The soil is a dark reddish clay loam with a low permeability. Soils of this type commonly exhibit permeabilities of 10^{-5} to 10^{-9} cm/sec (Freeze and Cherry, 1979). Borings taken in November of 1982 indicate that sand and gravel materials exist, either within the clay and silt matrix, or in thin lenses interspersed between clay and silt, and the soil gradually changes with depth into saprolite, a decomposed clay with a rich igneous horizon. Most of the horizon contains mica flakes and rock fragments. The saprolite material becomes coarser with depth and changes into silt-sized particles.

Bedrock consists of anorthosite, a gray, plutonic rock of Precambrian age that contains titanium-rich minerals in this locality. The bedrock strikes northeast and dips steeply to the southeast, and occurs at a depth of about 40 feet at the site.

Although limited data are available on the site hydrogeology, ground-water flow is apparently controlled by the geology of the valley. The inference is that the potentiometric surface slopes toward the river; hence, ground-water discharges to the river. Areas upgradient and north of the site appear to be free of ground-water contamination. Two wells located north and northwest of the site revealed no contamination. However, ground-water samples on and downgradient from the waste burial site showed contamination. Ground-water contamination is also evidenced by vegetative stress in the area.

The primary surface water of concern is the eastward-flowing river, which discharges into another river approximately 3.5 miles downstream. The surface water runoff from all six areas of concern discharges into this river. Several seeps have developed from the iron sulfate disposal area and apparently contaminate surface runoff flowing off the area and toward the river.

3.1.5 Bedrock Seeps and Springs: Municipal and Industrial Landfill

Description of Condition

The site was used as a municipal landfill and an industrial waste disposal site from 1966 to 1974. Materials were disposed of in unlined pits on the site, resulting in contamination of local soil, surface water, and ground water by organic and inorganic compounds.

Hydrogeologic Setting

The site lies on a plateau and is underlain by a sandstone, shale, and limestone formation. The bedrock stratigraphy beneath the site consists of the fractured and weathered sandstone underlain by the soft, grey-brown to reddish shale and claystones. A limestone lies below the shale resting conformably on "red beds." Soils at the site are 10-14 feet thick and consist mainly of silts and sands, probably derived from the bedrock.

The sandstone and the unconsolidated material overlying it constitute the uppermost aquifer. The limestone that underlies the shale is also an aquifer; although its water-bearing properties have not been directly investigated at the site, it is thought to be an unconfined aquifer.

Seeps have been identified at the contact of the sandstone and shale; the seeps are the result of infiltrating water that is unable to percolate through the less permeable shale and discharges on the slopes at the sandstone/shale contact. Seeps have also been identified at elevations typical of the limestone in the site area. Samples collected from one of the offsite seeps revealed concentrations of benzene, ethylbenzene, 1,3-dichloropropane, vinyl chloride, and trichloroethylene. This seep likely results from ground-water discharged at the sandstone/shale contact.

A contaminated spring also emerged at a neighboring farm. The elevation of the spring is typical of the elevation of the limestone; however, this unit has not been confirmed the source of discharge.

3.1.6 Basement Seepage Pathway: Quarry/Landfill Site

Description of Condition

A 125-acre site located in the Ohio River floodplain was an active sand and gravel quarry both before and during the period when the landfill was in operation from 1948 to 1975. In 1975, flash fires around water heaters were reported by families living in homes adjacent to the landfill. Seven families eventually had to be evacuated when explosive levels of methane gas were detected in the area. The presence of other toxic gases as well as methane were documented by Federal, State, and local authorities. In February of 1980, over 50 chemicals were identified when approximately 400 exposed drums were discovered on the river bank adjacent to the landfill. A venting system was installed in 1980 and the wastes were removed in 1981.

Hydrogeologic Setting

The site is underlain by relatively permeable alluvial deposits consisting of unconsolidated sands and gravels. Because of the site's proximity to the river, the water table is relatively close to the surface. The gases, such as methane that are generated by the decaying wastes tend to accumulate at or near the top of the aquifer.

3.1.7 Basement Seepage Pathway: Chemical Landfill Site

Description of Condition

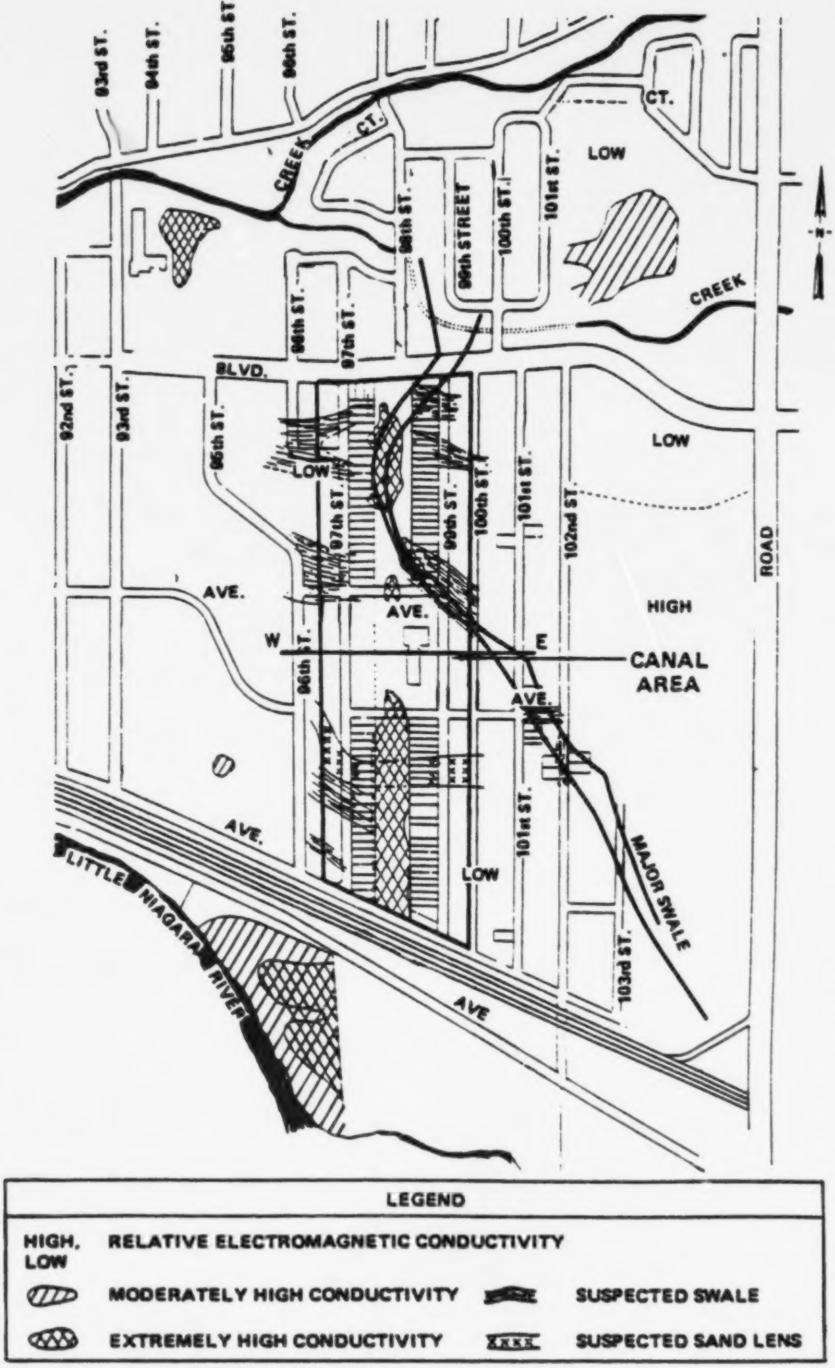
A canal, originally designed as part of a system to generate hydroelectric power, was used from the 1920s until the 1950s as a landfill for chemical wastes. Over 21,000 tons of various chemicals were dumped in the canal before the landfill was closed and covered in 1952. An elementary school and numerous homes were constructed near the site, and odors and residues were first reported during the 1960s. As the water table rose during the 1970s, these reports increased, and contaminated ground water began to seep out of the ground. Residents were relocated, the school was demolished, and millions cf dollars have been spent on efforts to clean up the site.

Hydrogeologic Setting

The hydrogeology of the site includes both shallow and deep groundwater flow systems. The shallow system, where most of the contamination occurred, consists of interbedded layers of silts and fine sands underlain by leaky confining beds of lacustrine clays and glacial till. The lower aquifer is a fractured dolomite bedrock, which overlies a relatively impermeable shale. Because of the relatively low permeability of the shallow system, a relatively long TOT_{100} to the deeper flow system is present at the site. Contaminated ground-water seepage occurred at the surface because of the "bathtub effect" described in Section 2.3.2. A detailed flow net that included the effects of engineered barriers, removal of the cover, and changes in infiltration rates would have revealed this shallow flow path and the potential for exposure. Refer to Figures 3.1-1 and 3.1-2.

3.2 HEALTH RISK ASSESSMENT METHODS

The health risk assessment methodology presented in this appendix focuses on the risks associated with the consumption of contaminated ground water. Although site-specific data were used to generate the risk estimates, the health assessments should not be construed to represent potential or actual risks to exposed populations. The risks associated with exposure to contaminants either on-site or off-site may be quite different from the risks projected here. The methodology does not quantitatively consider the exposure pathways of surface water and the basement seepage route. Also, several health risk routes of exposure (inhalation, skin absorption, ingestion) and other environmental media (air, soil) may be important factors in assessing risk for a particular site. Additional environmental impacts such as aquatic toxicity or damage to wetlands may be significant for a particular facility. However, for the purpose of evaluating a parameter to describe ground water vulnerability such as TOT_{100}, the health risk assessment methodology provides a way to perform


93rd ST.
94th ST.
95th ST.
96th ST.
CREEK
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LOW
98th ST.
99th STREET
100th ST.
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CREEK
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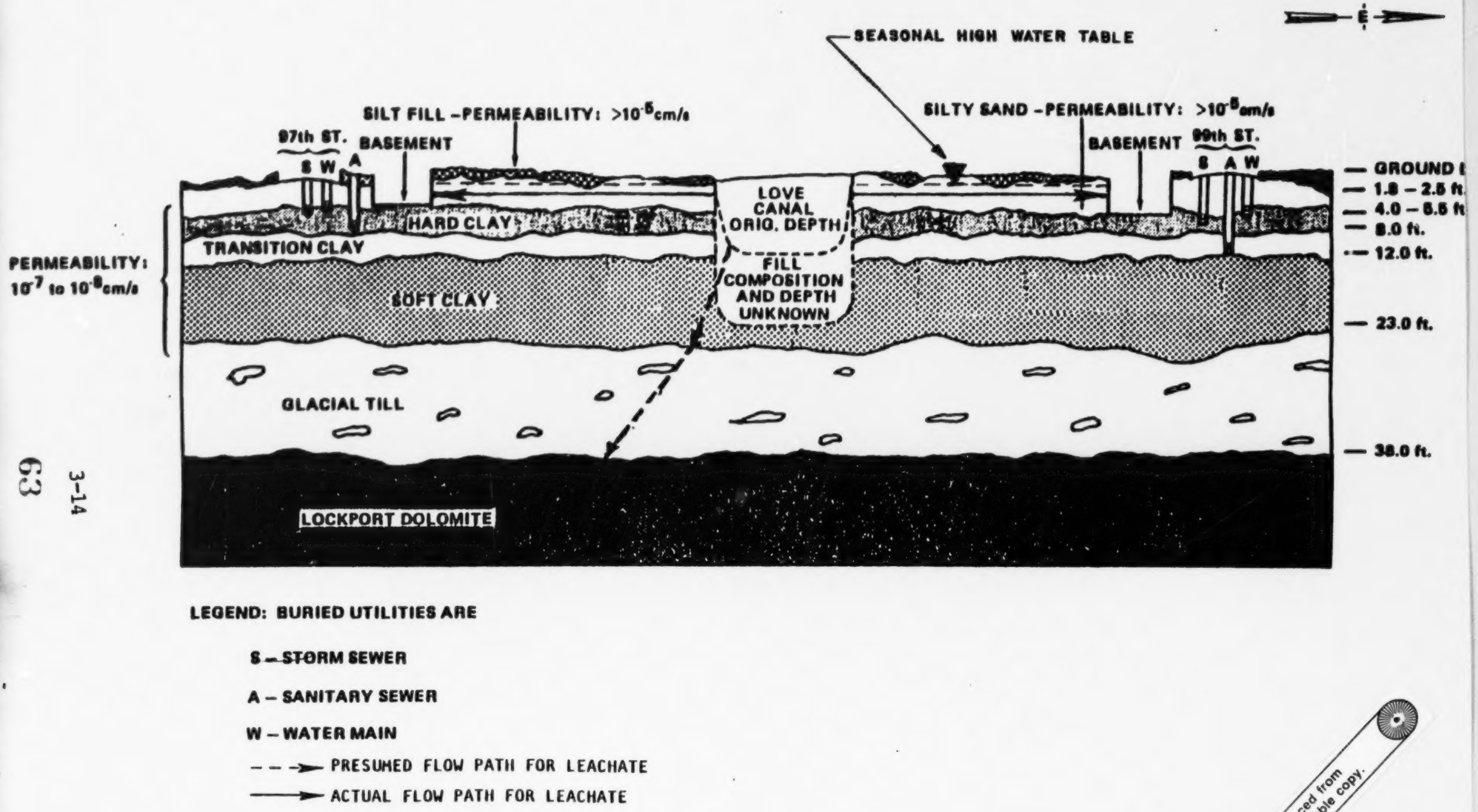
97th ST.
BLVD.
92nd ST.
93rd ST.
95th ST.
LOW
LOW
97th ST.
99th ST.
100th ST.
101st ST.
102nd ST.
ROAD
AVE.
AVE.
HIGH
W
E
CANAL
AREA
96th ST.
AVE.
AVE.
101st ST.
LOW
MAJOR SWALE
103rd ST.
LITTLE NIAGARA RIVER
AVE
LEGEND
HIGH, LOW
RELATIVE ELECTROMAGNETIC CONDUCTIVITY
MODERATELY HIGH CONDUCTIVITY
EXTREMELY HIGH CONDUCTIVITY
SUSPECTED SWALE
SUSPECTED SAND LENS

Figure 3.7-1. Site map showing location of E-W transect and major surficial features at Love Canal. (Adapted from EPA 600/4-82-030a).


E
SEASONAL HIGH WATER TABLE
SILT FILL -PERMEABILITY: $>10^{-5}$cm/s
SILTY SAND -PERMEABILITY: $>10^{-5}$cm/s
97th ST.
S W A
BASEMENT
BASEMENT
99th ST.
S A W
LOVE CANAL ORIG. DEPTH
FILL COMPOSITION AND DEPTH UNKNOWN
HARD CLAY
TRANSITION CLAY
SOFT CLAY
GLACIAL TILL
LOCKPORT DOLOMITE
PERMEABILITY: 10^{-7} to 10^{-8}cm/s
— GROUND
— 1.8 – 2.5 ft.
— 4.0 – 5.5 ft
— 8.0 ft.
— 12.0 ft.
— 23.0 ft.
— 38.0 ft.
LEGEND: BURIED UTILITIES ARE
S – STORM SEWER
A – SANITARY SEWER
W – WATER MAIN
- - -> PRESUMED FLOW PATH FOR LEACHATE
——> ACTUAL FLOW PATH FOR LEACHATE

Reproduced from best available copy.

Figure 3.7-2. West-East cross section of Love Canal (Looking North from a position located South of Wheatfield Avenue). Adapted from EPA 600/4-82-030a).

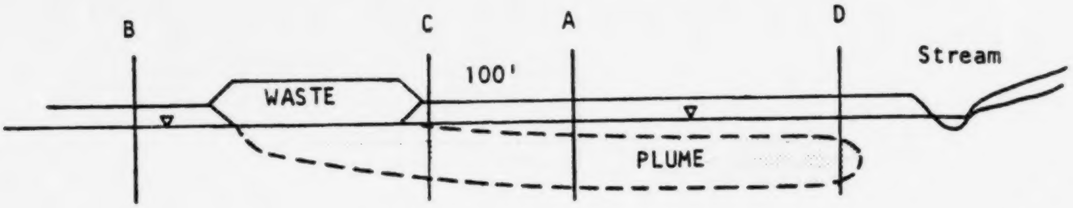
]

preliminary conservative risk calculations for ground-water contamination.

To facilitate the assessment of health risk, points of hypothetical exposure were chosen. Point B in Figure 3.2-1 represents background (or upgradient) ground-water quality. Individuals would be exposed to this water quality if no release from a hazardous waste management unit occurred. Hydrogeologic conditions at the site are assessed carefully to ensure that Point B does in fact represent an appropriate background position since it must be outside the influence of any potential ground-water mound associated with the unit. Point C represents ground-water quality at the RCRA "point of compliance" monitoring points (see 40 CFR 264.95). Point A is located at the end of a 100-foot-long ground-water flow line that originates beneath the unit. Where actual monitoring data are not available at a site for this point, data from the monitoring well located downgradient from the unit that is closest to Point A are used. Point D is site-specific, just within the leading edge of the plume.

Wherever possible, actual ground-water monitoring data for RCRA facilities are used in conjunction with well-characterized hydrogeologic descriptions. These data are available for a number of facilities within relatively fast ground-water flow regimes. Where such data are not available for important geologic settings, modeling techniques are used to estimate likely concentrations at steady-state conditions. Conservative assumptions for important parameters, such as dispersion, are used when modeling is necessary.

FIGURE 3.2-1: HYPOTHETICAL WELL LOCATIONS USED IN RISK ASSESSMENTS



where:

B = background water quality
C = compliance point water quality ("uppermost aquifer")
A = point 100 feet along flowline
D = point within leading edge of plume (point D may be within a stream)

NOTE: The distance from point C to point A need not be measured in the horizontal plane.

The objectives of these analyses are to determine:

- how large the plume is or may become,
- what the quality of water is within this plume,
- what the health risk would be to an individual withdrawing water from various locations in this plume for drinking purposes,
- whether the contamination has reached or will reach the uppermost aquifer,
- when the potential for exposure (and hence potential for adverse risk) could or did occur at these points.

3.2.1 Assessment Methodology

The health risk assessment case studies are based on analytical data available from ground-water monitoring at well-documented sites and ground-water quality data from computer simulation at partially or poorly documented sites. These data are listed in tables, along with the maximum actual or simulated concentration of significant contaminant compounds found at various monitoring points at each site. Ground-water quality data corresponding to positions A-D shown in Figure 3.2-1 are used to the extent possible in the health risk assessments.

The health risk assessment in this appendix does not consider actual or potential site-specific exposure of humans to groundwater, but instead considers a hypothetical exposure to groundwater at the positions indicated by points A-D at the sites. The risk calculation is intended to assess the potential health risk to individuals using ground water withdrawn at these points, and not to determine actual or potential risks to any populations residing near a land storage or disposal facility.

The hypothetical exposure scenario to be used for each risk calculation includes the following parameters:

- 70 kg (150 pound) adult,
- per capita consumption equals 2 liters of water per day,
- lifetime exposure (70 years), and
- consumption of untreated ground water.

These factors are used to determine the dose of chemicals that a person drinking water withdrawn from wells at points A-D would receive. The dose is defined as the amount of chemical taken into the body and is expressed in milligrams per kilogram body weight per day (mg/kg/day) or micrograms per kilogram body weight per day (g/kg/day). Only intake from drinking water is considered, although intake may occur from other sources, such as air and food. Intake is divided by the body weight in order to permit comparison. Pharmacokinetic factors such as absorption, body distribution, metabolism, and excretion are not considered in the calculation of dose. One hundred percent absorption is conservatively assumed for all contaminants.

The hypothetical exposure is calculated by multiplying the concentration of chemical in the ground water at the monitoring point (analytical data or simulated concentration) by 2 liters per day, and dividing by 70 kilograms. For example, drinking 2 liters per day of water containing 6 ppm of a contaminant would result in the following exposure:

$$6 \text{ ppm} = 6 \text{ mg/liter}$$

$$\frac{6 \text{ mg/liter} \times 2 \text{ liter/day}}{70 \text{ kg}} = 0.16 \text{ mg/kg/day}$$

After hypothetical exposures are calculated, conventional measures of human health risk are applied to the obtained values to assess hypothetical risks that humans would experience if they drank ground water withdrawn from wells at these positions. Health risks are calculated for each chemical found or predicted for which applicable health standards or guidelines exist. In addition to risk assessments for individual compounds, risks due to mixtures of noncarcinogenic compounds are calculated. Noncarcinogenic risks are considered to be independent of each other and additive. It is not possible to estimate, with any degree of confidence, the risks associated with exposure to multiple carcinogens; therefore, carcinogenic risks for single compounds only will be presented.

The health risk assessment methodology used in this appendix is considered conservative. However, caution should be exercised when assuming that determination of the dose of chemical to a hypothetical person drinking water withdrawn from points A-D is a conservative estimate of risk. Points A-D may not reflect worst case dose estimates at any particular time. In addition, only risk from ingestion is considered and intake from other sources may increase overall risk. While the methodology for noncarcinogens considers at additivity, synergistic and antagonistic effects are not considered and may result in different levels of risks. Again, assuming the methodology is employed only to give a measure of the magnitude of a hypothetical risk rather than to predict actual or potential risk to specific populations at specific sites, the methodology can be considered conservative and appropriate.

Two risk assessment methods are used, one for carcinogens and one for systemic toxicants. Carcinogens are defined as substances evaluated as human carcinogens or potential human carcinogens by the U.S. EPA Carcinogen Assessment Group (CAG, 1984) for which carcinogenic potencies have been developed. This list currently includes approximately 54 chemicals. The carcinogenic potency is used in a linear multi-stage model procedure for low-dose extrapolation (U.S. EPA, 1980). The risk estimates are calculated using the formula: Risk = Exposure x Potency. The model leads to a plausible upper limit (upper 95 percent confidence limit) of carcinogenic risk. It is based on a 70 kilogram person who drinks 2 liters of water per day over a 70-year lifetime. The risk value obtained represents increased carcinogenic risk over a person's lifetime from a single chemical.

For systemic toxicants, the analysis uses Acceptable Daily Intakes (ADIs) as contained in the Summary of Acceptable Daily Intakes (ADI) for Oral Exposure. (May, 1985). Some of the ADIs are considered interim by the EPA and are noted as such here. In some instances, two ADIs were presented for a single constituent. Where this was encountered for the constituents examined in the case studies, the more stringent ADI was used. Current EPA policy is to use ADIs for risk assessments involving systemic toxicants; in this appendix, ADIs are not calculated for carcinogens or suspected carcinogens.

ADIs are based upon laboratory animal studies and upon actual human exposure data where available. The ADI is usually calculated from a subchronic or chronic No Observable Adverse Effect Level (NOAEL) or Lowest Observable Adverse Effect Level (LOAEL) in laboratory studies. The NOAEL is the dose at which no toxic effects are observed in laboratory animals under experimental conditions. The LOAEL is the lowest dose at which an adverse response is observed. The NOAEL is a safer endpoint and the LOAEL is used only if a no effect dose has not been determined. The ADI is obtained by dividing the NOAEL or LOAEL by a "safety factor" of usually 10, 100, or 1,000, depending upon the quality and confidence level of the data. the most sensitive effect seen in a test animal is the toxic endpoint chosen for calculating ADIs.

To assess the effect of exposure to mixtures of systemic toxicants, the Hazard Index was used (Federal Register (Vol. 50, No. 6, pp 1170 -1176)). For a single substance, this index is the ratio of the estimated daily intake to the ADI. For a mixture of toxic substances, these ratios are summed. A Hazard Index in excess of 1.0 is considered to be unacceptable. The following equation represents a Hazard Index for a mixture of systemic toxicants:

$$HI = E_1/AL_1 + E_2/AL_2 + \ldots + E_i/AL_i$$

where,

E_i = exposure level to the i^{th} toxicant, and

AL_i = maximum acceptable levels for the i^{th} toxicant

At some sites, very high concentrations of chemicals (such as 3,4 dimethylphenol) that do not have specifically quantified toxicity values are present in ground water. Assessing the toxicity of these chemicals is done, when appropriate, by assuming toxicities equal to that of an isomer, if quantified, or to the most toxic member of the chemical family, if quantified.

The risk values calculated for exposure to carcinogens and systemic toxicants determine whether hypothetical exposure to ground-water at each site represents a potential threat to human health.

For carcinogens, data are presented as per person incremental risks given as negative powers of 10. A risk of 1×10^{-6} means that, upon lifetime exposure to two liters of water per day containing the specified concentration of the carcinogen, a person incurs an increased risk of developing cancer of one in 1 million. A risk of 4.3×10^{-5}, for example, means an increased risk of 4.3 in one hundred thousand. A 1 in 1 million increased risk means that each individual who is exposed to the ground water over his or her lifetime has an additional (i.e., incremental) chance of getting cancer of 1 in 1 million.

There is no current EPA policy as to the level of risk that is acceptable. In its Ambient Water Quality Criteria, EPA calculated concentrations of carcinogens in water that would give increased incremental risks of 1×10^{-5}, 1×10^{-6}, and 1×10^{-7} to people exposed to such water over their lifetimes. The selection of these risk levels did not imply their acceptability. Because carcinogens are assumed not to have a threshold dose (a level below which exposure does not elicit a response), any exposure to a carcinogen carries with it a risk of developing cancer.

Systemic toxicants, on the other hand, have threshold dose-response curves; a threshold dose exists below which a toxic response is not seen (the NOAEL). The chronic or subchronic

NOAEL divided by a safety factor is assumed to provide an adequate margin of safety for lifetime human exposure. Therefore, any daily exposure lower than the ADI is assumed to carry no risk of toxic effects in the general population, based upon currently available data. A daily exposure greater than the ADI (a Hazard Index equal to or greater than 1.0) carries some risk of toxicity upon chronic exposure.

3.2.2 Methods for Interpreting Results

Hypothetical risks are calculated for monitoring points A, C, and D to determine the incremental contributions made by the hazardous waste management units. After this calculation, the potential for actual human exposure to ground-water at points A, C, and D is assessed. The known or modeled spatial distribution of the plume over this distance is compared with the hydrogeologic characteristics of the site to determine whether the plume is associated with geologic units that have a reasonable chance of serving as a source of drinking water, of transmitting the plume to surface waters, or of entering nearby streams.

The lateral extent of the plume (as determined by the location of Point D) at steady-state conditions also serves as an indicator of the potential for exposure. These distances are compared qualitatively for a variety of geologic settings to describe those settings that offer the greatest and least potential for exposure. Sites are grouped into two categories. The first consists of those at which a potential for exposure exists and in which ground-water quality poses an adverse risk to a hypothetical user. The second consists of sites at which the plume will remain entrained for a very long time in a geologic unit that is not a reliable source of water and at which the other two pathways of exposure do not appear to be significant. These ratings are compared with the TOT_{100} values calculate for the cases to evaluate how well the TOT_{100} test results correlated with these categories. This comparison is used to refine the definition of vulnerability.

The hydrogeologic information and data used in the case study evaluations are not all-inclusive. That is, the information presented may not necessarily describe the entire facility area. For instance, only one or two "representative" cross-sections were used in each case study. Because there are on-going investigations at these sites, full sets of data are not yet available. The case study interpretations and evaluations are not meant to replace or be equivalent to comprehensive Part B permit application reviews for meeting the ground-water protection requirements of 40 CFR Part 264, Subpart F.

3.2.3 Results of Preliminary Exposure and Health Risk Assessments

OSW is compiling and studying information drawn from a collection of 228 hazardous waste management facilities across the U.S. and is categorizing these facilities by geologic setting. This study will include an examination of flow patterns and an assessment of current and future health risk to potential ground-water users. Time of Travel and the maximum potential dimensions (distance between the unit and point D) of plume growth for facilities representative of the various settings will also be estimated.

Section 3.3 presents information for six facilities. Health risk assessments for potential ground-water users at five of these facilities were made using actual monitoring data. An analytical model has been used to describe potential contaminant concentrations at the sixth site and to supplement the monitoring data at one of the other sites.

3.3 CASE STUDIES: HEALTH RISK ASSESSMENT

The following case studies discuss the health risk assessments using the detailed assessment methodology described in Section 3.2, primarily for the ground water pathway. However, when exposure through surface water or the basement seepage pathway is possible, this fact is noted.

Summary of Case Studies

The case studies presented below describe a range of TOT_{100}s and exposure potentials. Case study D-1 illustrates horizontal flow in a shallow glacial till aquifer where a long TOT_{100} and naturally saline ground-water correspond to a very low exposure potential. Case study D-2 describes a plume that travels through an alluvial aquifer and discharges to a nearby river; TOT_{100} is short, and potential exposure via the first pathway would be high except for the restricted aquifer use and an industrial setting. The full impact on the second pathway is unknown. Case study D-3 shows how a very long TOT_{100} through a thick chalk sequence yields a very low exposure potential for all pathways. A short TOT_{100} through an unconfined upper aquifer is illustrated in case study D-4; however, exposure is limited due to surrounding land use. Case study D-5 shows how a short TOT_{100} in an unconfined aquifer causes contamination of a nearby bay and a high exposure potential for the first two pathways. Case study D-6 shows a complex setting of a recharge zone where fractured bedrock strongly affects ground-water flow, and where a short TOT_{100} corresponds to known exposures through the first pathway to nearby residents.

Although the case studies do not include an example of a long TOT_{100} setting where exposure potentials are high, EPA is investigating further. The possibility exists that a site initially characterized as a long TOT_{100} location could have exposure potential due to unforeseen channeling of ground-water through the third pathway. This channeling could occur through thin sand lenses, fissures, and manmade conduits. Although thorough characterization of the hydrogeology of the site should preclude this happening, a long TOT_{100} setting may need further evaluation to eliminate the possibility of exposure through a hidden pathway.

3.3.1 Case Study D-1

Facility Description

The facility is located near a major river in the Great Lakes Region and has been used since 1942 for a variety of industrial purposes including commercial hazardous waste disposal. The site was used during 1942 and 1943 for the manufacture of trinitrotoluene (TNT). Subsequently, it was used for: the storage and transport of chemicals and ammunition, the storage and burial of radioactive materials, and the burial and burning of wastes from the development of high energy fuels. Figure 3.3-1 depicts some of the waste unit locations.

The current facility operations include the treatment, recovery, disposal and transfer of hazardous and industrial wastes. The waste units include a waste receiving area, metal hydroxide storage ponds, chemical treatment facilities, biological treatment lagoons, transfer stations and nine landfills, one of which is presently in operation. The operating landfill is the major source of potential ground-water contamination.

Leachate data from the landfills indicate that the most common organic constituents are methylene chloride, toluene, trichloroethene, 1,1,1-trichloroethene, benzene, tetrachloroethene and chloroform. Methyl ethyl ketone, tetrahydrofuran, phenol and some PCB compounds were also detected.

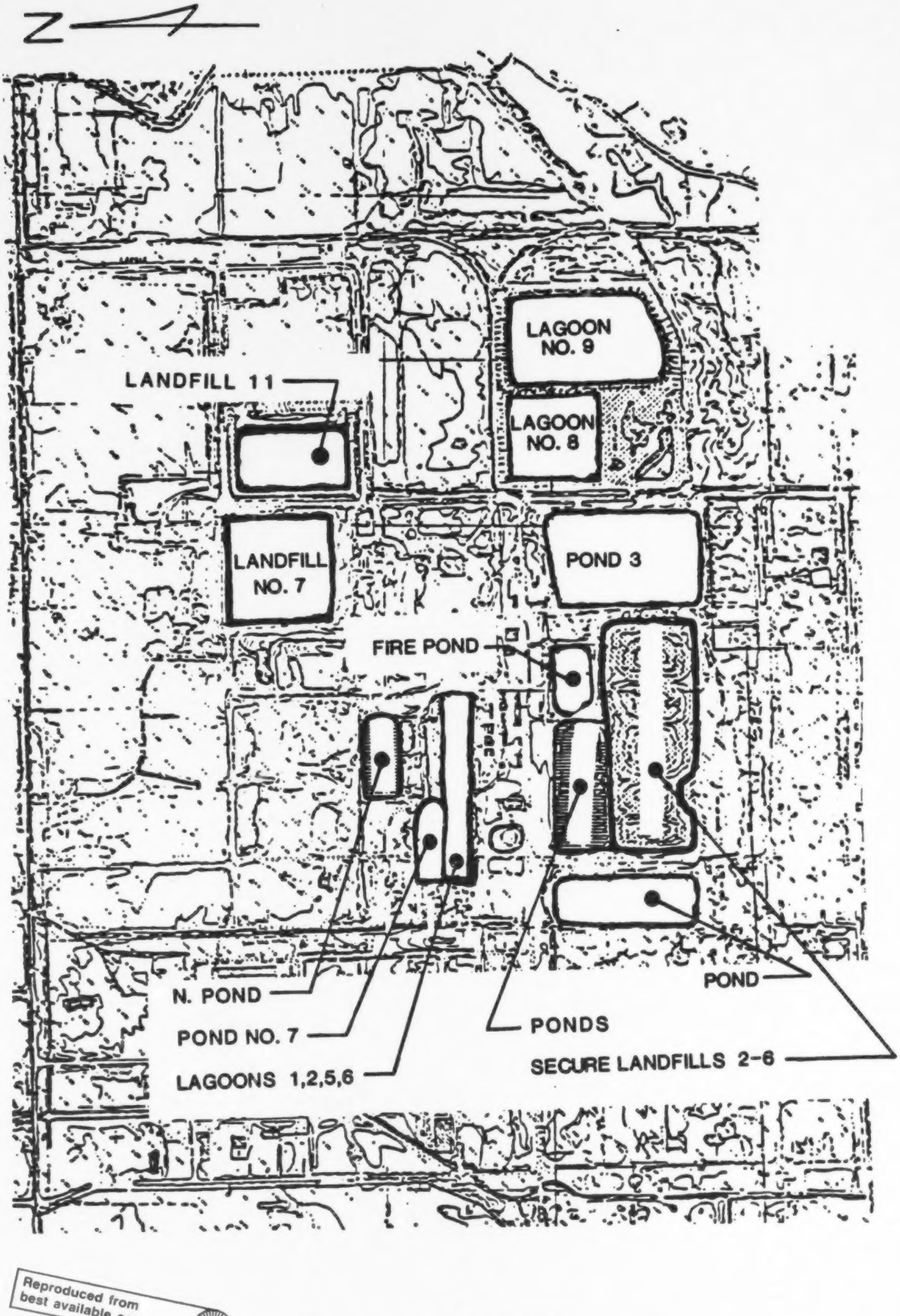

N
LAGOON NO. 9
LANDFILL 11
LAGOON NO. 8
LANDFILL NO. 7
POND 3
FIRE POND
N. POND
POND NO. 7
LAGOONS 1,2,5,6
PONDS
POND
SECURE LANDFILLS 2-6

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FIGURE 3.3.1 WASTE UNITS

Topography/Climate

The facility lies on the lowland area of a lake plain. The lake plain has a gentle slope of approximately 0.3 percent toward the north; the slope begins at an elevation of 375 feet at the base of an escarpment and drops to an elevation of 275 feet. The plain varies in width from about 6.5 miles to 10 miles. The facility is located in an area of low relief. The site slopes between 0.1 and 0.2 percent toward the north; surface drainage is generally the north through several small creeks.

Precipitation is fairly uniformly distributed throughout the year; the wettest month is August, which accounts for approximately 12 percent of the total precipitation. Data for the area indicate about 31.5 inches of precipitation for water year 1983, while the potential evapotranspiration was estimated at 25.4 inches for the same year.

Regional Geology/Hydrology

The bedrock units in this region are comprised of a series of Upper Devonian to Silurian aged shales, limestones and dolostones. The rock units are relatively flat-lying with a regional dip of approximately 0.75% south - southwest.

The unconsolidated deposits include alluvium overlying glacial deposits from several major periods of glaciation. In some areas, these deposits have been re-distributed by streams. In addition, the irregularity of the glacial deposits has led to a varied drainage pattern with many lakes, ponds, bogs and marshes. The major drainage direction in the region is toward the Great Lakes and the St. Lawrence River.

The glacial deposits constitute the best aquifers within the region; limited ground water is available from bedrock aquifers in areas where the unconsolidated deposits are absent, thin, or of low permeability.

Site Geology

The geology of the site area has been characterized by information gathered during several field investigations. More than 450 borings and test pits from several site studies were used by the permit applicant to describe the geology of the area. Figure 3.3-2 is a geologic cross section drawn from the northwest to the southeast portion of the site.

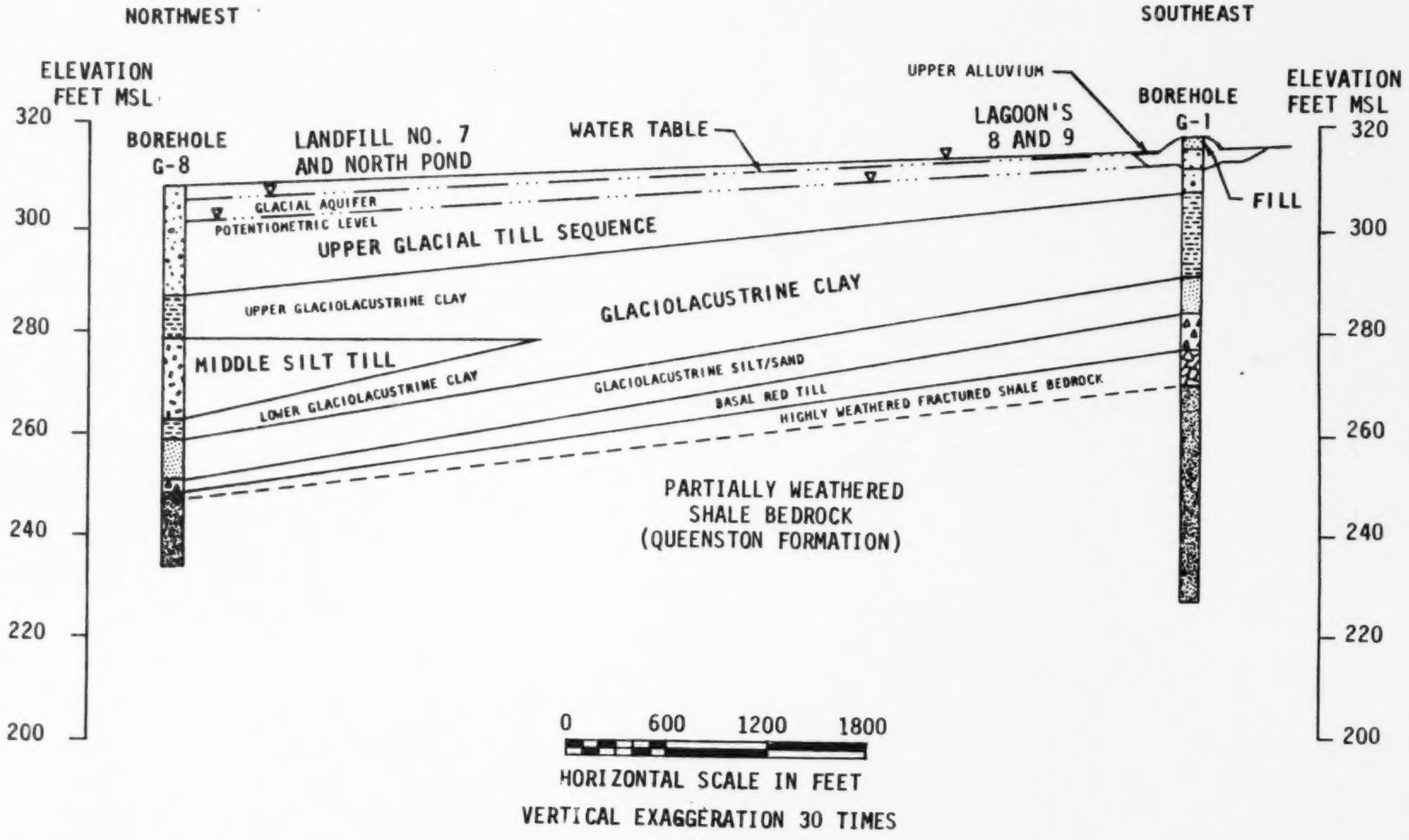
Surficial Geology

The facility is underlain by about 30 to 60 feet of glacial deposits overlying shale bedrock.

The uppermost unit at the site is a low permeability glacial till sequence that is about 10-25 feet thick in the site area. The till is underlain by a glaciolacustrine clay, 20-30 feet thick in most areas, which is in turn underlain by a glaciolacustrine silt/sand unit. Beneath these units is a lodgement till that overlies the shale bedrock.

At the northwestern portion of the site the glaciolacustrine clay unit is divided into an upper and lower member by a silt till that was apparently deposited during a local oscillation of the advancing glaciers.

FIGURE 3.3-2 GEOLOGIC CROSS SECTION


NORTHWEST
SOUTHEAST
ELEVATION FEET MSL
320
300
280
260
240
220
200
BOREHOLE G-8
LANDFILL NO. 7 AND NORTH POND
WATER TABLE
UPPER ALLUVIUM
LAGOON'S 8 AND 9
BOREHOLE G-1
FILL
GLACIAL AQUIFER
POTENTIOMETRIC LEVEL
UPPER GLACIAL TILL SEQUENCE
UPPER GLACIOLACUSTRINE CLAY
GLACIOLACUSTRINE CLAY
MIDDLE SILT TILL
LOWER GLACIOLACUSTRINE CLAY
GLACIOLACUSTRINE SILT/SAND
BASAL RED TILL
HIGHLY WEATHERED FRACTURED SHALE BEDROCK
PARTIALLY WEATHERED SHALE BEDROCK (QUEENSTON FORMATION)
0
600
1200
1800
HORIZONTAL SCALE IN FEET
VERTICAL EXAGGERATION 30 TIMES

NOTE: This figure is a schematic representation of the geologic stratigraphy made by straight line interpolation between boreholes G-1 and G-8. Some of the strata shown are discontinuous.

Bedrock Geology

Bedrock encountered during drilling in the site area is a reddish-brown shale that is approximately 1000 feet thick. Rock samples were cored from some of the borings on the site. The cores reveal that the rock is generally a red fissile shale that has occasional bands of green shale ranging from 1/2 to 24 inches thick, and gypsum nodules 1/2 inch to 1 inch in diameter.

The top 5 to 10 feet of the shale unit is highly weathered and fragmented. Although some cores showed that the shale was broken parallel to bedding, it was difficult to determine whether this was due to natural bedding features of the rock or if it was induced by drilling. Some high angle joints which were not a result of drilling were observed in some of the unweathered cores.

The surface of the bedrock is undulating; it slopes from an elevation of about 275 feet MSL, in the southeastern part of the site, to 250 feet MSL in the northwestern portion of the site.

The average values for hydraulic conductivity are 1×10^{-5} cm/sec in the shallow rock and 5×10^{-6} cm/sec in the deeper rock zones.

Site Hydrology

Shallow ground water occurs in the upper glacial till sequence at a depth of about 3 to 5 feet. Potentiometric contours in the upper glacial till indicate that the shallow ground water moves horizontally north - northwest. Vertical flow in the upper glacial till is minimal due to the underlying less permeable glaciolacustrine clay. The glaciolacustrine clay is the main retarding layer to downward vertical flow in the site area.

Vertical gradients across the glaciolacustrine clay unit range from 0.1 to 0.58 with a mean of 0.35.

Flow in the glaciolacustrine silt/sand aquifer is essentially horizontal to the north and west. The most transmissive portion of the aquifer is its thickest portion, where a coarser sub-unit is present. As the ground water flows northward, it moves toward the areas of higher transmissivity. Figure 3.3-3 depicts flow directions in the glaciolacustrine silt/sand aquifer.

Flow within the basal red till is controlled by pressure differences within the glaciolacustrine silt/sand aquifer and the underlying bedrock. The shallow bedrock exhibits flow that is predominantly horizontal toward the north and west, similar to flow in the glaciolacustrine silt/sand aquifer. The shallow bedrock has low hydraulic conductivity and is not considered a significant water-producing zone when compared to the glacial aquifer.

The average values for flow rates for the geologic units at the site as presented in the Part B application are given in Table 3.3-1. The flow velocities were calculated using values for hydraulic conductivities, hydraulic gradients, and effective porosity. Conductivities of the geologic formations were determined in the field through variable head tests and in the laboratory. Gradients were established using ground-water level measurements obtained from wells and piezometers at the site. A value of oil for effective porosity was supplied by the applicant and is applied to all the units. Since it is unlikely that all the units would have the same effective porosity, TOT values

FIGURE 3.3-3 Glaciolacustrine Aquifer

Potentiometric Contours

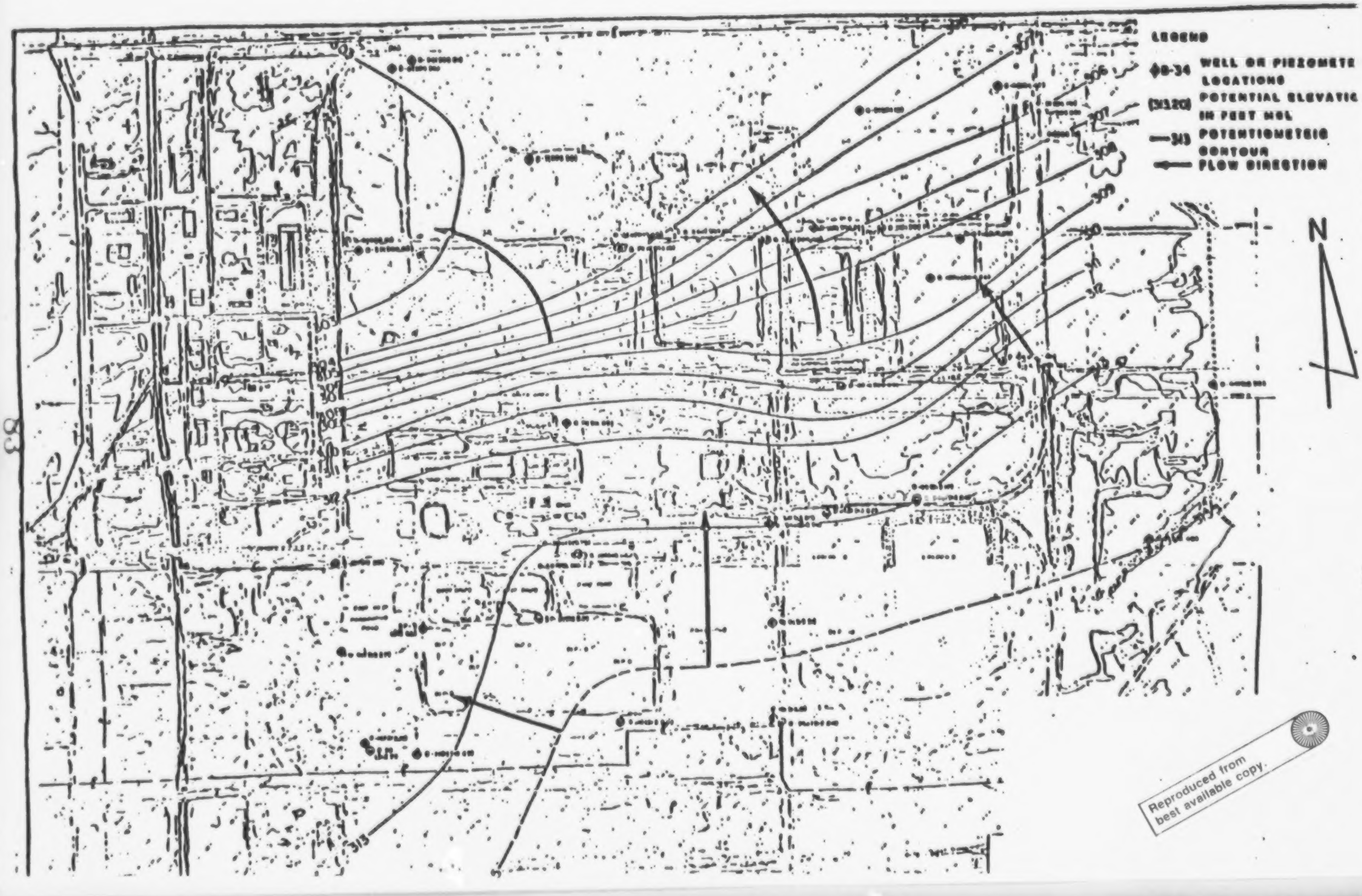

LEGEND
B-34 WELL OR PIEZOMETE
LOCATIONS
(312.0) POTENTIAL ELEVATIC
IN FEET MSL
—313 POTENTIOMETRIC
CONTOUR
FLOW DIRECTION
N
305
306
307
308
309
310
311
312
313

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TABLE 3.3-1 ESTIMATED FLOW RATES AND VOLUMES

GEOLOGIC(1) FORMATION	PERMEABILITY, K (cm/s)		GRADIENT, I (ft./ft.)		FLOW AREA, A (ft.^{2})		FLOW VOLUME(4) Q (ft.^{3}/day)		FLOW RATE, v(5) (ft./yr.)	
	Horizontal	Vertical	Horizontal(2)	Vertical	Section(3)	Plan	Horizontal	Vertical	Horizontal	Vertical
UGT	$2x10^{-6}$	$6x10^{-7}$(6)	0.002	0.012	80,000	$16x10^{6}$	1.0	320	0.04	0.07
GC	$5x10^{-8}$	$2x10^{-8}$	0.001	0.35	40,000	$16x10^{6}$	0.006	320	0.0005	0.07
MST	$3x10^{-6}$	$1x10^{-7}$	0.005	0.07(7)	60,000	$7x10^{6}$	3	140	0.16	0.07
GSS	$2x10^{-4}$(8)	$2x10^{-4}$(8)	0.007	$6x10^{-6}$(7)	90,000	$16x10^{6}$	360	50	14.5	0.01
BRT	$4x10^{-8}$	$3x10^{-8}$	0.004	0.04	40,000	$15x10^{6}$	0.02	60	0.002	0.01
SR	$1x10^{-5}$	-	0.004	-	160,000(9)	-	18.1	-	0.41	-

NOTES

(1) Formation Designations:

UGT - Upper Glacial Tills
GC - Glaciolacustrine Clay
MST - Middle Silt Till
GSS - Glaciolacustrine Silt/Sand
BRT - Basal Red Till
SR - Shallow Rock

(2) Exit gradient from property.

(3) Cross section area along north or north and west perimeter for each formation.

(4) $Q = kIA$.

(5) $V = kI/n_e$, with $n_e = 0.1$.

(6) $k_v = 6x10^{-7}$ cm/s due to structural discontinuities. (See text Sections 7.1 and 8.3.)

(7) Estimated to maintain continuity.

(8) Coarse portion of aquifer with $k_v = k_h$.

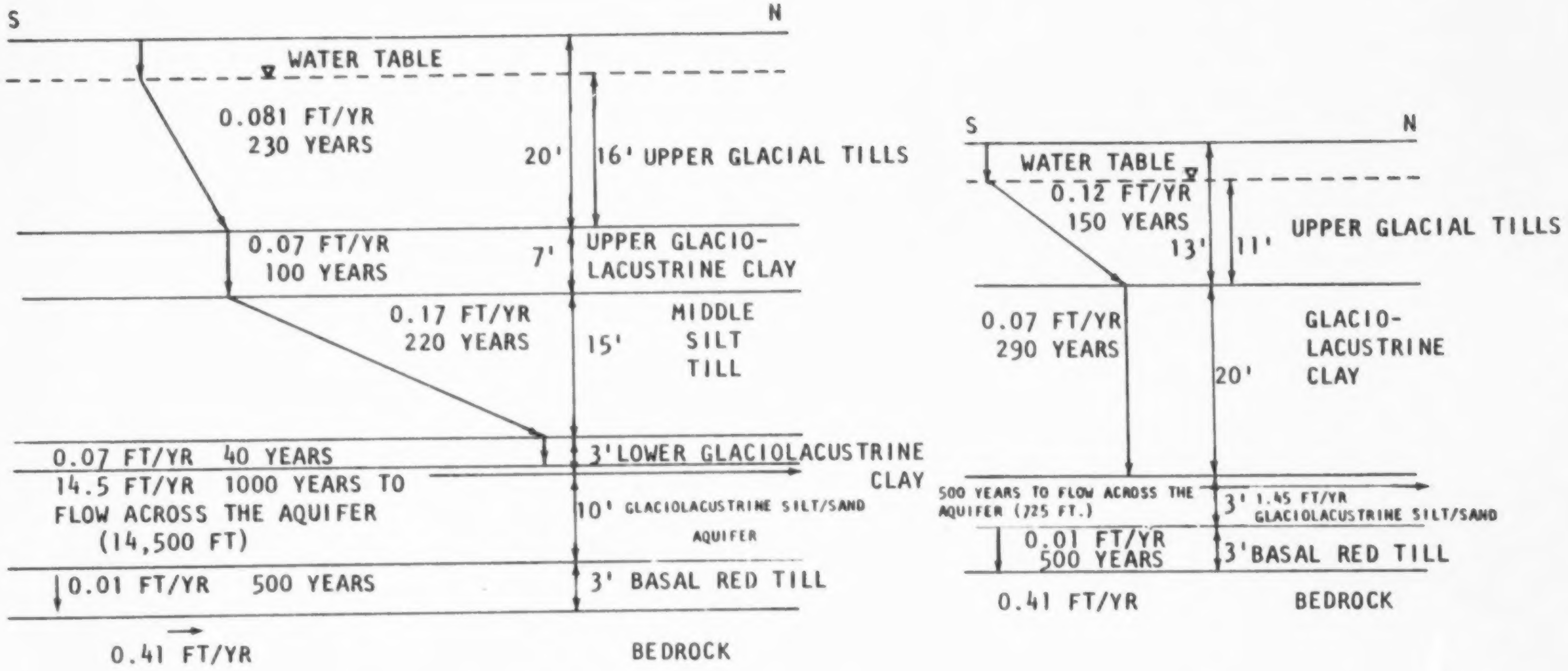
(9) Assumed 20 feet thick.

calculated with this input should be considered to be only estimates. A second TOT has been calculated using default values for effective porosity for each unit.

A contaminant can be traced from the point of release at the surface through the geologic formations in the site area. Horizontal and vertical flow rates can be added, using vector addition, to get the resultant flow rate vector through the different units (see Figure 3.3-4). Figure 3.3-4 also depicts two different profiles of flow, for the northwest and the southeast sides of the facility. Ground-water time of travel through the geologic units varies between these opposing sides of the facility because of different unit thicknesses and the presence of the middle silt till at the northwest side of the facility. The middle silt till is absent at the southeast side of the facility.

At the southeast side of the facility, the upper glacial till layer is thinner (approximately 11 feet thick) than at the northwest side (approximately 16 feet thick). Using average flow rates derived from vector addition, the ground water would take 150 years to flow through that layer. At the northwest side, the ground water would take 230 years to flow through the upper glacial till unit, because of the greater unit thickness.

Flow within the upper glacial till is toward the north-northwest. Assuming that a particle is released and will be carried with the ground water without being affected by advective or dispersive forces, after 100 years, the particle will still be traveling through the upper glacial till layer toward the north-northwest. The time that the particle would take to reach the


S
N
WATER TABLE
0.081 FT/YR
230 YEARS
20'
16' UPPER GLACIAL TILLS
0.07 FT/YR
100 YEARS
7'
UPPER GLACIO-LACUSTRINE CLAY
0.17 FT/YR
220 YEARS
15'
MIDDLE SILT TILL
0.07 FT/YR 40 YEARS
3' LOWER GLACIOLACUSTRINE CLAY
14.5 FT/YR 1000 YEARS TO FLOW ACROSS THE AQUIFER (14,500 FT)
10' GLACIOLACUSTRINE SILT/SAND AQUIFER
0.01 FT/YR 500 YEARS
3' BASAL RED TILL
0.41 FT/YR
BEDROCK
S
N
WATER TABLE
0.12 FT/YR
150 YEARS
13'
11'
UPPER GLACIAL TILLS
0.07 FT/YR
290 YEARS
20'
GLACIO-LACUSTRINE CLAY
500 YEARS TO FLOW ACROSS THE AQUIFER (725 FT.)
3' 1.45 FT/YR GLACIOLACUSTRINE SILT/SAND
0.01 FT/YR
500 YEARS
3' BASAL RED TILL
0.41 FT/YR
BEDROCK

NORTHWEST SIDE OF FACILITY

(Velocities from TABLE 2.3-1
Scale - 1" = 10' HOR.
1" = 10' VER.

SOUTHEAST SIDE OF FACILITY

(Velocities from TABLE 2.3-1 except UPPER GLACIAL TILLS and AQUIFER velocities based on horizontal gradients 0.005 and 0.0007 respectively)
Scale - 1" = 10' HOR.
1" = 10' VER.

FIGURE 3.3-4 SCHEMATIC FLOW DIAGRAM

glaciolacustrine silt/sand aquifer is 590 years for the northwest side of the facility and 440 years for the southeast side of the facility.

TOT_{100} Calculation

TOT_{100} can be calculated by adding the number of years as shown in Figure 3.3-4 to travel through the geologic units underlying the site. It will take 590 years to travel 55 feet along a flow path to the glaciolacustrine silt/sand unit at the northwest side of the facility. When it reaches this unit, the ground water moves horizontally at a rate of 14.5 ft/year. To complete the total distance of 100 feet, ground water must travel an additional 45 feet through the unit. At a rate of 14.5 ft/year, the added travel time is three years. Thus, the total estimated travel time over 100 feet at the northwest side of the facility is 593 years.

TOT_{100} calculation using n_e default values

	Effective Porosity Default Values	TOT
Upper Glacial Tills	0.05	115 years
Upper Glaciolacustrine Clay	0.01	10 years
Middle Silt Till	0.10	220 years
Lower Glaciolacustrine Clay	0.01	4 years
Glaciolacustrine Silt/Sand	0.15	4.5 years
	TOT_{100} =	353.5 years

Using default values of effective porosity (see Table 3.2-2 of the main text) for each layer rather than a constant effective porosity of 0.1 throughout produced a difference in TOT_{100} of 239.5 years. As such the percent error involved is too large

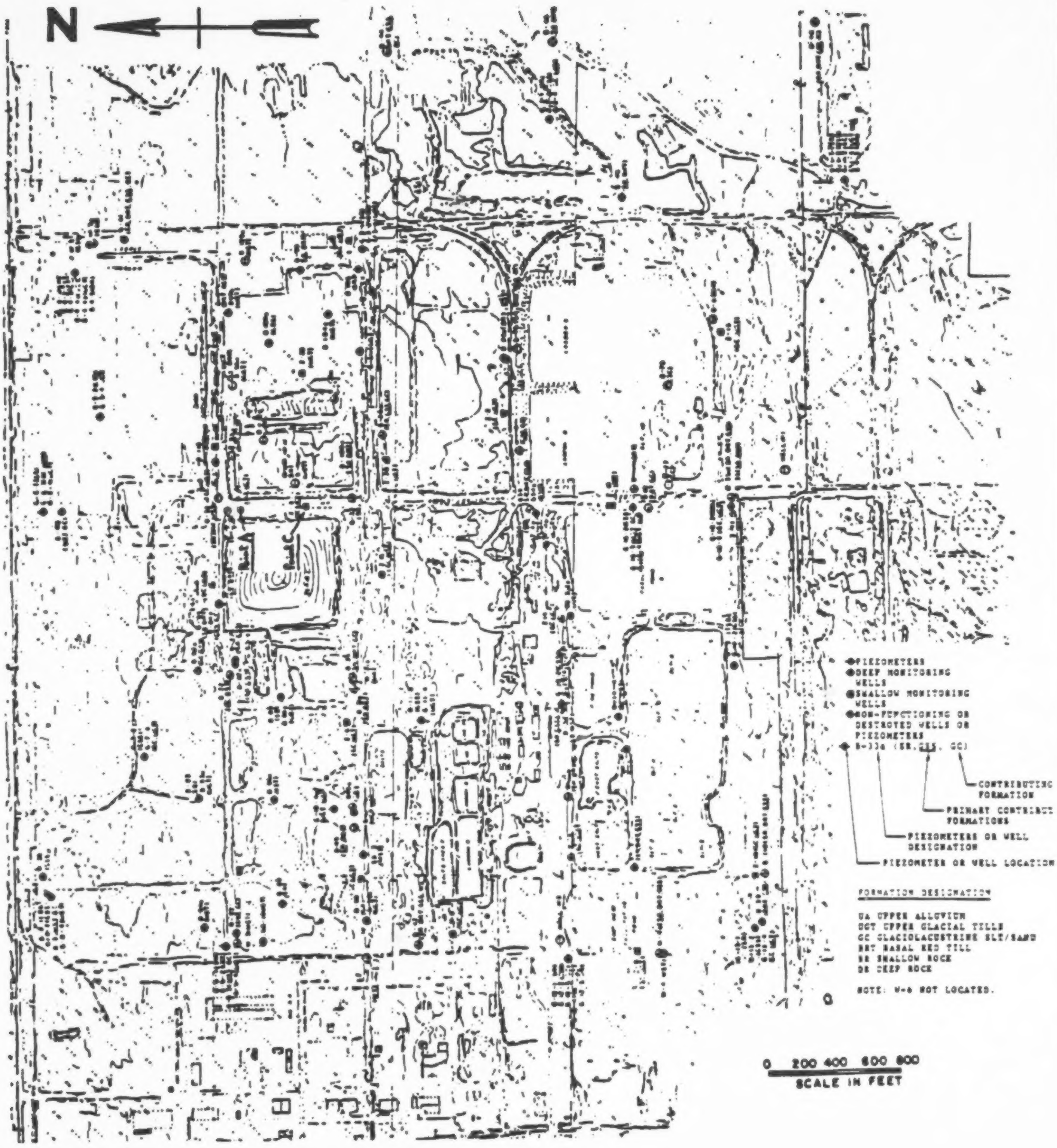

N
PIEZOMETERS
DEEP MONITORING WELLS
SHALLOW MONITORING WELLS
NON-FUNCTIONING OR DESTROYED WELLS OR PIEZOMETERS
B-33a (SR, UGT, GC)
CONTRIBUTING FORMATION
PRIMARY CONTRIBUT FORMATIONS
PIEZOMETERS OR WELL DESIGNATION
PIEZOMETER OR WELL LOCATION
FORMATION DESIGNATION
UA UPPER ALLUVIUM
UGT UPPER GLACIAL TILLS
GC GLACIOLACUSTRINE SLT/SAND
BRT BASAL RED TILL
SR SHALLOW ROCK
DR DEEP ROCK
NOTE: W-6 NOT LOCATED.
0 200 400 600 800
SCALE IN FEET

FIGURE 3.3-5 WELL AND PIEZOMETER LOCATION PLAN AND FORMATION INTERVALS

(when using a constant effective porosity value) to recommend its use.

Plume Information

The monitoring well network at this site consists of over 50 shallow and deep wells located to serve a detection monitoring function. The shallow wells draw from the upper glacial till layer and the deep wells draw from the various deeper formations. Ground-water monitoring has been performed on a monthly basis for two years, drawing samples from a selection of the monitoring wells on the site. There is no conclusive evidence of a contaminant plume at this site, but isolated contamination has been observed at individual wells.

Only one well has shown contamination in repeated samples that is not explained by laboratory error or solvents used in well grouting materials. This well, shallow well Z-3 (screened in the upper glacial till), is considered to be point C in this case study. The nearest downgradient well, point A also screened in the upper glacial till aquifer, is represented by well Z-21, 300 feet north of Z-3. These wells are located between secure landfill (SLF) 7 and SLF 11, shown in the upper portion of Figure 3.3-5. The observed contaminant levels at these well are presented in Table 3.3-2.

There are no suitable wells to represent points B or D. No wells are located offsite or far enough downgradient from the facility to characterize contaminant migration. However, since no contaminant plumes have been detected, this is not necessary.

Likewise, no wells are located far enough upgradient from the potential sources of contamination to serve as background wells. However, background concentrations for the constituents reported in Table 3.3-2, are clearly below the limits of detection.

Health Risk Assessment

Of the two contaminants observed at well Z-3, one is recognized as a carcinogen and the other is a systemic toxicant. Trichloroethylene is a carcinogenic substance with a potency, recommended by the Carcinogen Assessment Group (CAG), of 1.9×10^{-2}. Lifetime ingestion of 2 liters per day of water with an average trichloroethylene concentration of 668 ppb (the average of the three samples) represents a 3.6×10^{-4} probability of contracting cancer.

The acceptable daily intake for 1,2-trans-dichloroethylene is 0.001 mg/kg/day. The highest of the concentrations observed at well Z-3 corresponds to an exposure of 0.0027 mg/kg/day and a hazard index of 2.7. This concentration would therefore pose an unacceptable health risk if it were present in a drinking water supply.

Several of the deeper wells on the site showed barium concentration in excess of the 1 ppm, National Interim Primary Drinking Water Standards value. However, these concentrations appear to be a background condition since some of these wells are located upgradient of the hazardous waste management units, and since the travel time to some of the deep wells is over 500 years.

Exposure Assessment

The exposure potential at this facility is considered to be very low. There is no known contaminant plume, the TOT is very long, and the ground-water beneath the facility is very saline, in excess of state drinking water standards. The ground waters are not currently used as a source of drinking water, and no such use is expected in the future.

Table 3.3-2: Contaminant Concentration (ppb)

Constituent	Point C (Well Z-3)			Point A (Well Z-21)		
	6/84	11/84	12/84	6/84	11/84	12/84
1,2 Trans-dichloroethylene	ND	60	95	ND	ND	ND
Trichloroethylene	1290	496	258	ND	ND	ND

ND denotes not detected. The limits of detection were 10 ppb.

3.3.2 Case Study D-2

Facility Description

The facility started operations in 1952 and covers an area of approximately 2.4 sq. miles in the southeastern U.S. (see Figure 3.3-6). This area contains manufacturing facilities in conjunction with past, present, and proposed waste treatment, storage, and disposal units. Some of the units currently onsite consist of an incinerator, numerous storage tanks, a landfill, and a biological sludge landfill.

No information was available concerning the types of wastes disposed of in the landfill unit. However, it is known that operations at this facility have contaminated the uppermost alluvial aquifer; therefore, the facility is implementing a Corrective Action Plan as specified under 40 CFR 264.100. This plan proposes closure of many of the units in an attempt to eliminate the source or sources of contamination and installation of a pumping well system to contain contaminant migration.

Site Topography

The site consists of rolling topography with gentle slopes to the southeast toward the river. Many small streams and drainage ditches dissect the site. Surface water flow from northwest of the property is diverted through drainage ditches to the east into the river. Surface flow from within the site follows the site topography to the southeast into the river.

Site Climate

The climate of the area is very humid and sub-tropical. There are very long, hot, and humid summers with mild wet winters. The average annual precipitation is 59 inches, with December through April being the wettest and August through November being the driest. The average temperature for this area is 65°F January averages 49°F while July averages 80°F.

Regional Geology

The site is located in the Gulf Coastal Plain Physiographic province adjacent to the river. The area is underlain by alluvium and terrace deposits of Pleistocene age. Deposits also included in this area are undifferentiated Miocene sand, clay, and gravelly sand. Total thickness of these unconsolidated flood plain terrace deposits are over 700 feet.

Site Geology

Data from previous and recent test drilling indicate that the plant site is built on a flood plain terrace, whereas the lower portion of the facility located near the river is built on flood plain deposits. A pervasive clay layer is reported at the surface of the facility. This is reportedly well documented from previous reports; however, the large distances between wells as shown in Figure 3.3-7 indicate that very little control in the form of wells or borings is available for interpretation of the cross sections. Cross section locations are shown on Figure 3.3-8. Directly below this surficial clay are lenticular deposits of silt, sand, and clay. Previous reports (May 1981) allude to the fact that there may be a hydraulic connection through the clay between

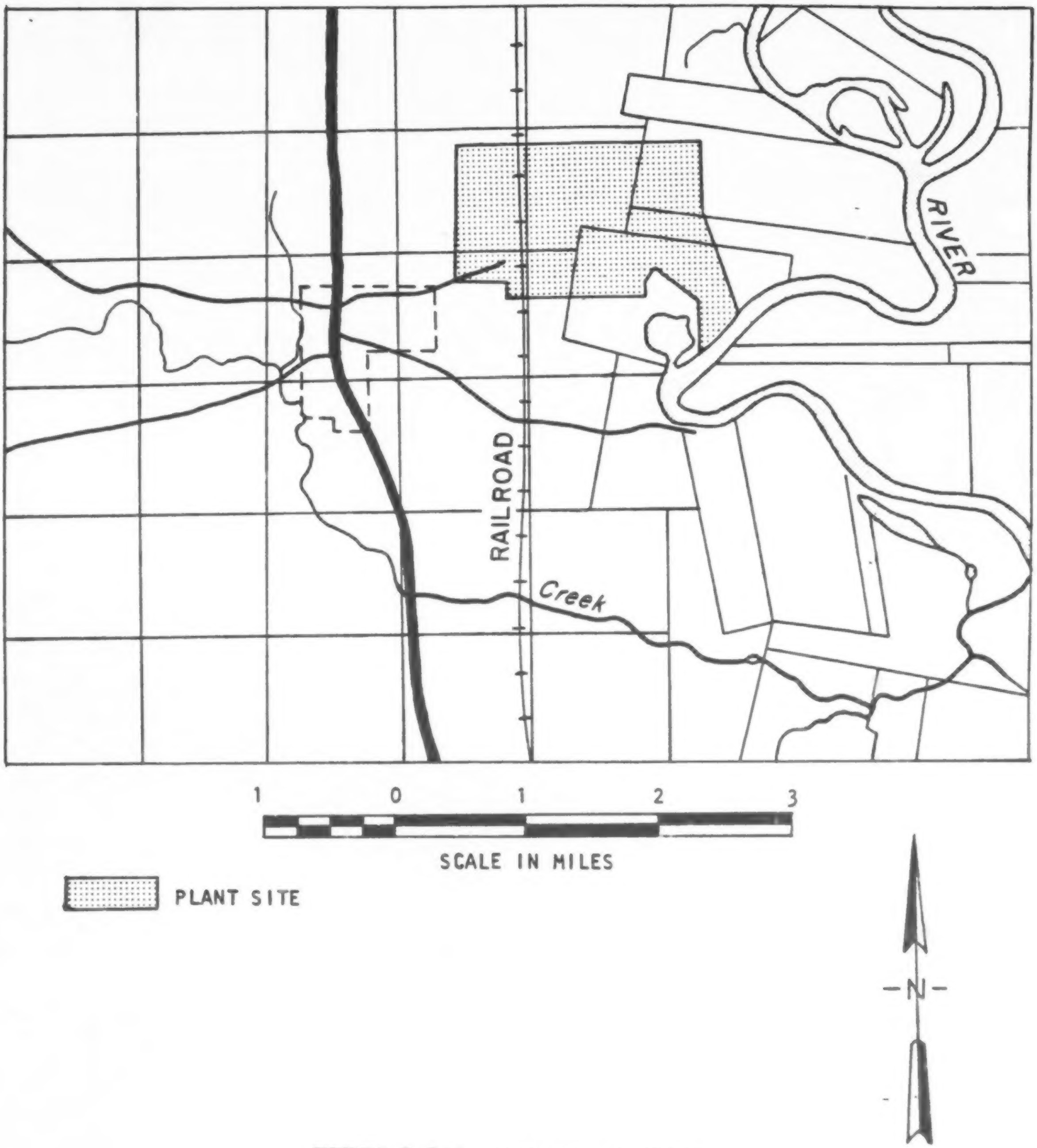

RIVER
RAILROAD
Creek
1
0
1
2
3
SCALE IN MILES
PLANT SITE
N

FIGURE 3.3-6 FACILITY LOCATION

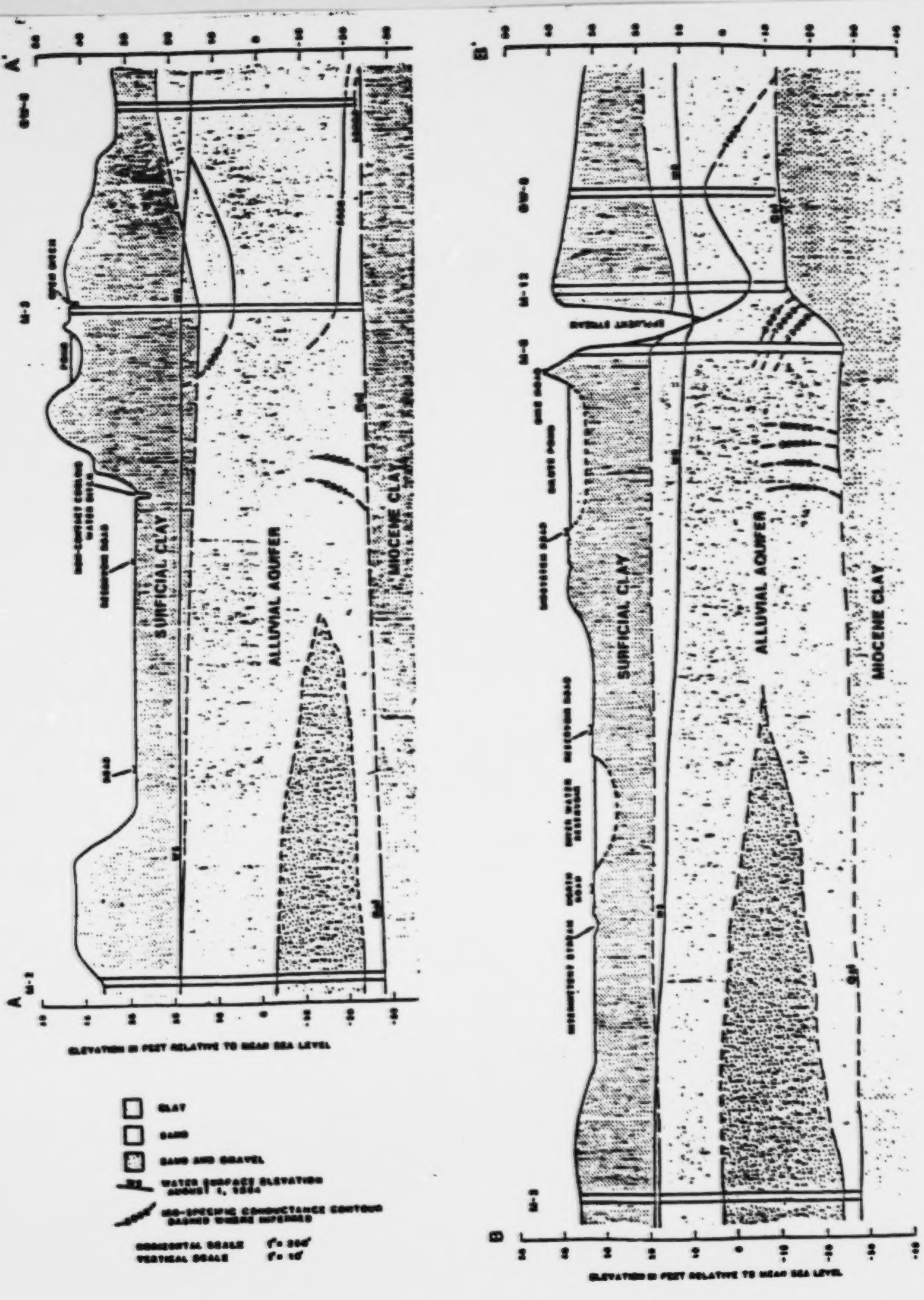

A
A'
B
B'
SURFICIAL CLAY
ALLUVIAL AQUIFER
MIOCENE CLAY
ELEVATION IN FEET RELATIVE TO MEAN SEA LEVEL

FIGURE 3.3-7 HYDROGEOLOGIC CROSS SECTION A-A' AND B-B'

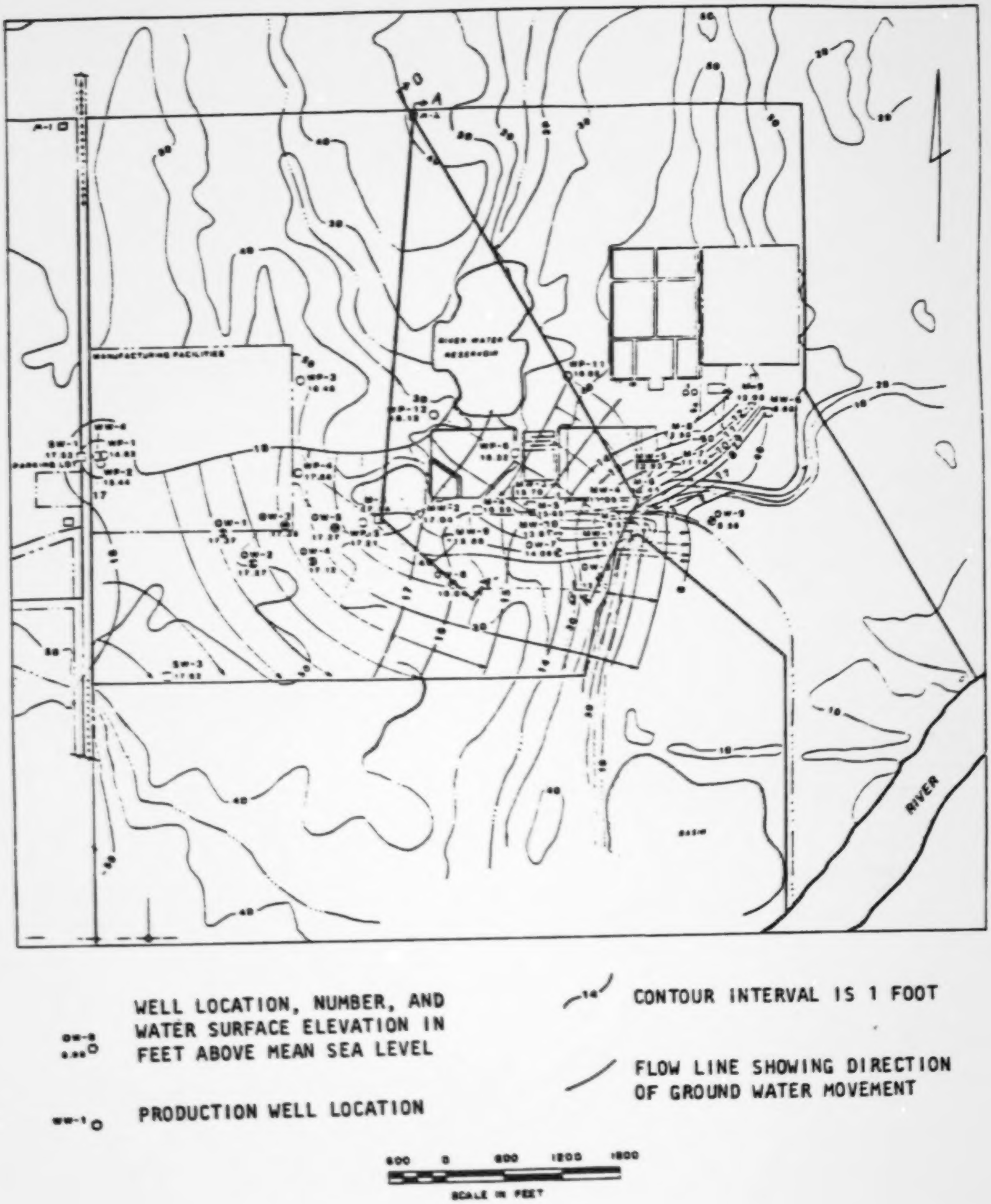

RIVER WATER RESERVOIR
MANUFACTURING FACILITIES
PARKING LOT
SW-1 17.82
WP-1
WP-2
WP-3
WP-4
WP-11
WP-12
OW-1 17.37
OW-2 17.37
OW-3
OW-4
OW-5
SW-3 17.82
BASIN
RIVER
WELL LOCATION, NUMBER, AND WATER SURFACE ELEVATION IN FEET ABOVE MEAN SEA LEVEL
PRODUCTION WELL LOCATION
CONTOUR INTERVAL IS 1 FOOT
FLOW LINE SHOWING DIRECTION OF GROUND WATER MOVEMENT
600 0 600 1200 1800
SCALE IN FEET

FIGURE 3.3-8 FLOW NET ANALYSES FOR THE ALLUVIAL AQUIFER, AUGUST 1984

the water table and fluids in the reservoir. The basis for this statement is reportedly from water level data, but these data were not available for review.

The surficial clay materials are underlain by Recent and Pleistocene shallow terrace and alluvial deposits. As shown in the cross sections (Figure 3.3-7), this unit is the uppermost aquifer and consists of alternating, interbedded layers of sand, gravel, and clay. Underlying this alluvium is a sequence of Miocene clays and sandy clays with thicknesses ranging from 30 to more than 100 feet. Below these clays are alternating layers of Miocene age sand, clay, and gravel over 700 feet thick. This unit is the second aquifer identified in the area. There is no mention of the bedrock underlying this facility. The Miocene clay layer is reported to be a confining layer separating the upper alluvial aquifer from the lower Miocene sandy aquifer.

Site Hydrology

Ground water parameters have been defined at the site through the use of many existing wells (M series wells) from previous studies and through the installation of nine 2 inch diameter observation wells (OW-1 through OW-9). Most of the observations contained in this report are directed at the uppermost alluvial aquifer. The only mention of the surficial clay layer is that permeabilities range from 0.7×10^{-8} to 1.9×10^{-7} cm/sec. There is no discussion in the report addressing to what extent the clay layer impedes flow into the alluvial aquifer. However, the application indicates a "water surface" in the cross-section (Figure 3.3-7) which is described as the alluvial aquifer water table. It can be seen in the cross section that an area labeled effluent stream is in direct contact with the alluvial aquifer. This may be a pathway for migration as evidenced by elevated contaminant concentrations in well M-6.

Ground water in the uppermost aquifer is reported to be under semi-confined conditions and flowing to the southeast towards the river (see Figure 3.3-8).

The underlying Miocene aquifer is also confined and reported to contain highly mineralized water. Due to the overlying low permeability Miocene clay layer (10^{-8}/sec) the applicant states that the upper alluvial and Miocene aquifers are not hydraulically connected. Therefore, contamination in the uppermost aquifer would not migrate to the Miocene aquifer for a long time.

Due to pumping from wells at the facility and adjacent property, the hydraulic head in the Miocene and alluvial aquifers have been greatly impacted. Prior to ground-water development, the potentiometric surface in the Miocene aquifer was higher than that in the alluvial aquifer. Today, the Miocene potentiometric surface elevations are below that of the upper alluvial aquifer. Flow directions in the Miocene aquifer are also reported to be somewhat influenced due to its development as a ground-water resource.

Field tests were performed in an attempt to define the hydraulic parameters of the alluvial aquifer. Twelve hour specific capacity tests were performed on wells M-3, M-4, M-6 and M-12, with results ranging from 14.15 to 25.5 gallons per minute per foot of drawdown.

Aquifer (pump) tests (96 hours) were performed on wells W-3 and W-12 in order to define transmissivity, hydraulic conductivity and coefficients of storage. A summary of the test results is presented in Table 3.3-3. These wells are reported to be screened in the uppermost alluvial aquifer, and, therefore, listed parameters are indicative of this unit.

Time of Travel

A worst case TOT_{100} was calculated for flow in the uppermost alluvial aquifer using the following parameters:

	Worst case K Value	Average K Value	Default Value (Freeze & Cherry, 1979)
Hydraulic Conductivity (K) Time drawdown and recovery tests (Pump tests)	288 ft/day	90 ft/day	10^{-1}cm/sec
Hydraulic gradient (i) water level measurements	.01	.01	.01
Effective Porosity EPA default value	.20	.20	.20
Ground water velocity (v)	14.4 ft/day	4.5 ft/day	14.2 ft/day
TOT_{100}	7 days	22 days	7 days

The above TOT_{100} does not take into account the surficial clay layer due to the fact that the effluent stream shown in the cross sections (Figure 3.3-8) is in direct connection with the alluvial aquifer. Due to this feature, contamination could reach the alluvial aquifer without moving through the clay layer. However, there are hazardous waste units located in the clay that do not breach through to the alluvium. Therefore, a TOT incorporating the clay is presented below:

TABLE 3.3-3 SUMMARY OF PUMPING TEST RESULTS

Well Number	Discharge Q (gpm)	Distance from PW to EW 1/ r (feet)	Saturated Thickness m (feet)	Coefficient of Transmissivity T (gpd/ft)	Coefficient of Permeability K (gpd/ft^2)	Coefficient of Storage S (-)	Remarks
M-3	78	-	38	1,117	29	-	Time-drawdown
	78	-	-	3,973	104	-	Time-drawdown
	78	-	-	8,939	235	-	Time-recovery
M-4	90	-	25.8	55,751	2,161	-	Time-drawdown
M-6	88	-	34.56	49,200	1,424	-	Time-drawdown
M-12	75.5	-	22	4,326	197	-	Time-drawdown
	75.5	-	-	9,832	447	-	Time-recovery
MW-11	75.5	22.5	22	18,026	819	6.33×10^{-1}	Time-drawdown
			AVERAGE:	18,895.5	676.87		

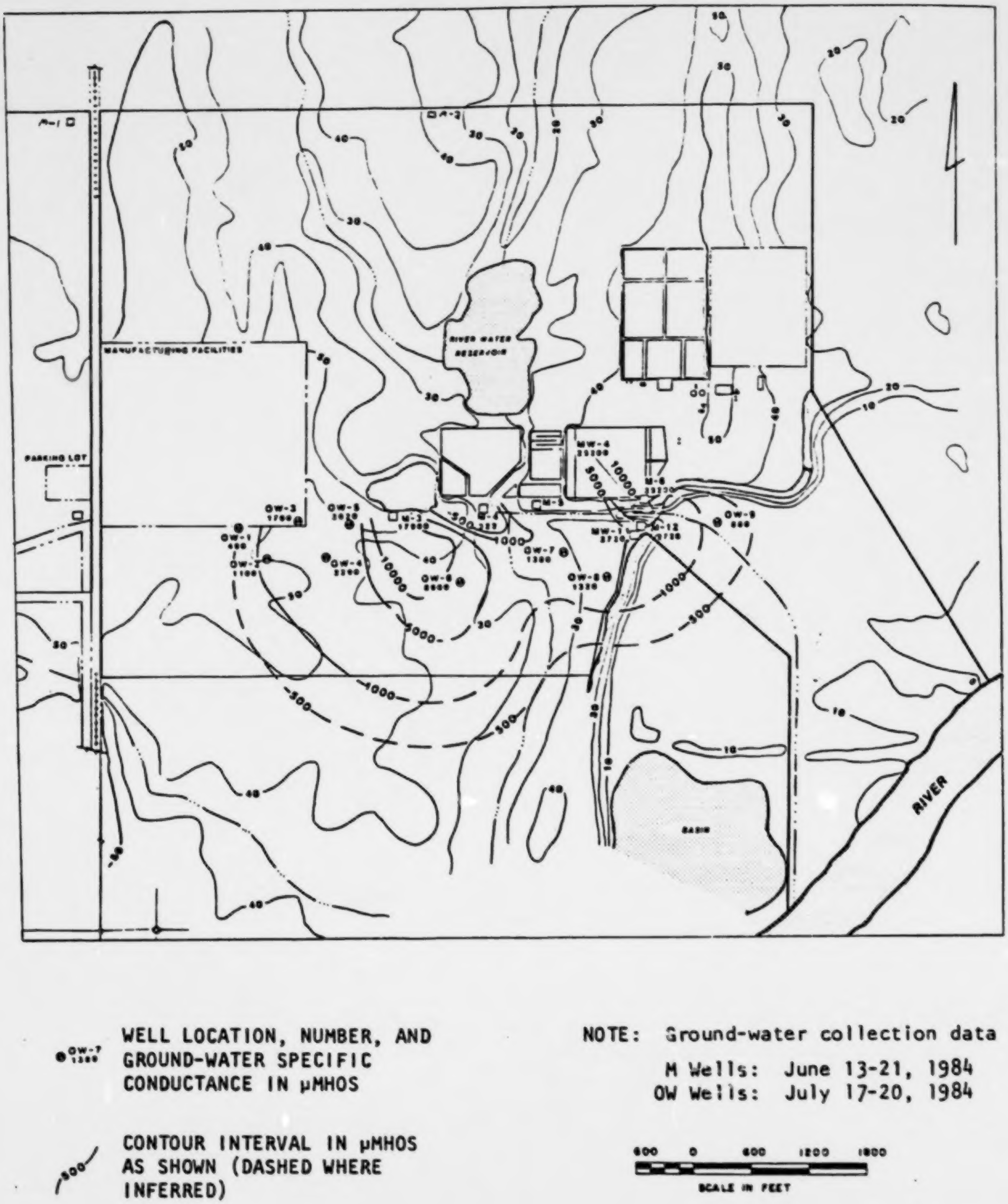
1/ PW, pumping well;
EW, evaluation well

$K = 1.9 \times 10^{-7}$ cm/sec (lab methods)	Permeability value stated in the May 1981 report.
$n = .01$	Default value from EPA location guidance for effective porosity.
$i = 1.0$	Assuming vertical flow through the clay layer (worst case).

Using the expression, $v = \frac{Ki}{ne}$, a velocity of .05 ft/day was calculated. Assuming that the clay unit is 20 ft. thick it would take approximately 400 days for groundwater to travel through this unit into the uppermost aquifer.

Plume Information

The indicator parameters used to delineate the plume consist of specific conductance, total organic carbon (TOC) and total organic halogen (TOX). Figure 3.3-9 shows results of the specific conductance testing, while Figure 3.3-10 shows locations of wells tested and compliance point monitoring wells. From the various monitoring results there appears to be a line of contamination with two lobes of increased contamination. One appears to be concentrated near the manufacturing area with its source presumably being an abandoned effluent pond. There is no discussion concerning the nature of this pond and, therefore, very few conclusions can be drawn concerning the contamination. Due to the fact that contamination is lower in OW-1 than OW-2, it is possible that the plume has past and there is not a continued source. However, without historical monitoring data, no definite conclusion can be drawn concerning this issue. The other plume appears to be in the area of the effluent stream (Figure 3.3-9).


MANUFACTURING FACILITIES
PARKING LOT
RIVER WATER RESERVOIR
BASIN
RIVER
OW-1
OW-2
1100
OW-3
1700
OW-4
OW-5
OW-6
OW-7
1300
OW-8
OW-9
M-2
17000
M-3
M-4
M-5
M-12
MW-1
MW-4
10000
5000
1000
500
50
40
30
20
10
600 0 600 1200 1800
SCALE IN FEET

WELL LOCATION, NUMBER, AND GROUND-WATER SPECIFIC CONDUCTANCE IN μMHOS

CONTOUR INTERVAL IN μMHOS AS SHOWN (DASHED WHERE INFERRED)

NOTE: Ground-water collection data

M Wells: June 13-21, 1984
OW Wells: July 17-20, 1984

FIGURE 3.3-9 ISO-SPECIFIC CONDUCTANCE MAP FOR THE ALLUVIAL AQUIFER, JULY-JUNE 1984

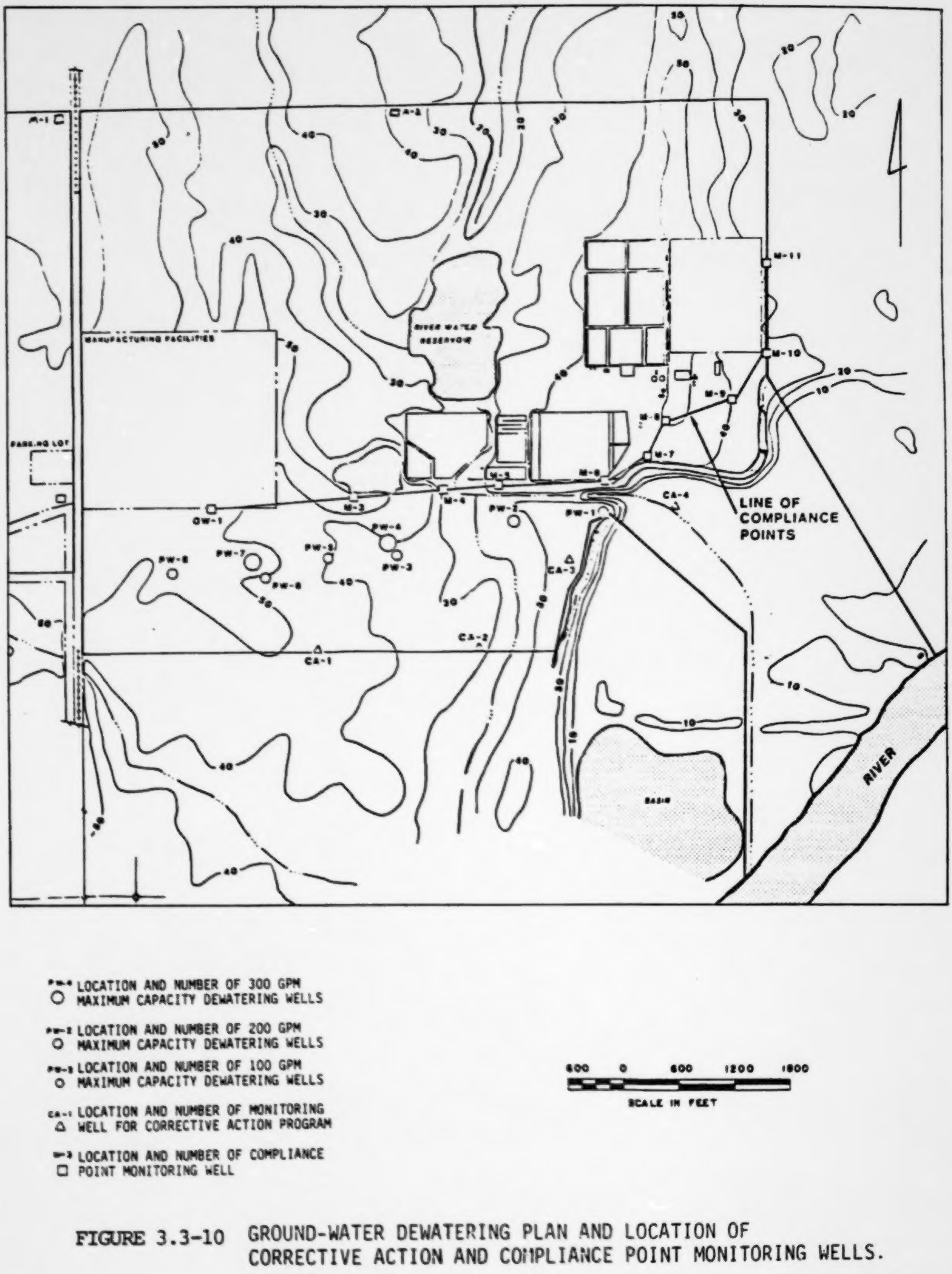

M-1
A-2
MANUFACTURING FACILITIES
PARKING LOT
RIVER WATER RESERVOIR
OW-1
M-3
M-4
M-5
M-6
M-7
M-8
M-9
M-10
M-11
PW-1
PW-2
PW-3
PW-4
PW-5
PW-6
PW-7
PW-8
CA-1
CA-2
CA-3
CA-4
LINE OF COMPLIANCE POINTS
BASIN
RIVER
10
20
30
40
50
PW-4 LOCATION AND NUMBER OF 300 GPM MAXIMUM CAPACITY DEWATERING WELLS
PW-2 LOCATION AND NUMBER OF 200 GPM MAXIMUM CAPACITY DEWATERING WELLS
PW-3 LOCATION AND NUMBER OF 100 GPM MAXIMUM CAPACITY DEWATERING WELLS
CA-1 LOCATION AND NUMBER OF MONITORING WELL FOR CORRECTIVE ACTION PROGRAM
M-3 LOCATION AND NUMBER OF COMPLIANCE POINT MONITORING WELL
600
0
600
1200
1800
SCALE IN FEET

FIGURE 3.3-10 GROUND-WATER DEWATERING PLAN AND LOCATION OF CORRECTIVE ACTION AND COMPLIANCE POINT MONITORING WELLS.

It is interpreted that contamination has been released from various waste management units in this area.

Well M-2 is located upgradient of the facility and is designated as well B (background) in the A, B, C, D configuration. Since there are two plumes or plume sources, wells OW-1 (point C-1) and OW-2 (point A-1) will be used to identify the plume from the manufacturing area while well M-6 (point C-2) and well M-12 (point A-2) will be used to identify the plume on the eastern side of the facility. No D wells at this facility have been designated. Table 3.3-4 shows contaminant concentrations at selected wells.

B. Health Risk Assessment

Several hazardous constituents have been observed in the two plumes originating at this site. Table 3.3-4 presents concentrations of hazardous constituents observed in selected monitoring wells M-2 (point B) OW-1 (point C-1), OW-2 (point A-1), M-6 (point C-2) and M-12 (point A-2).

Carcinogenic constituents were observed in wells M-6, OW-2 and M-12. The carcinogenic risks are tabulated in Table 3.3-5 for each of these wells. The most significant risk at each of these well is due to high levels of arsenic. (Arsenic has been associated with skin cancer in epidemiological studies.) The highest risk, 4.6×10^{-2} was observed at well OW-2, a few hundred feet downgradient from the compliance well near the manufacturing facility. In the plume originating at the hazardous waste management unit, the compliance point (M-6) shows a carcinogenic risk

TABLE 3.3-4 CONTAMINANT CONCENTRATIONS AT SELECTED WELLS (ppb)

Constituents	M2 (6/84)	M6 (4/84)	M6 (6/84)	M12 (4/84)	OW2 (6/84)
Purge & Trap Compounds					
Benzene	ND	--	118	--	838
Carbon disulfide	ND	--	40.6	--	<10
Chloroethane	ND	--	43.8	--	ND
Chlorobenzene	ND	--	ND	--	29469.6
Chloroform	ND	--	140.8	--	938.8
1,2-Trans-dichloroethylene	ND	--	<10	--	ND
Methylene chloride	ND	--	40.4	--	10.2
trans-1,3-Dichloropropene	ND	--	ND	--	<10
Methyl ethyl ketone	ND	--	114.4	--	24.6
Carbon tetrachloride	ND	--	ND	--	306.6
Toluene	ND	--	9344	--	17
Trichloroethylene	ND	--	34.5	--	ND
Tetrachloroethylene	ND	--	ND	--	<10
Acid/B/N/Pest Compounds					
Aniline	ND	--	ND	--	<10
bis(2-Ethylhexyl)phthalate	ND	--	<10	--	ND
1,3,5-Trichlorobenzene	ND	--	ND	--	<10
2,3,5,6-Tetrachlorophenol	ND	--	<10	--	ND
2,3,4,5-Tetrachlorophenol	ND	--	<10	--	ND
o-Cresol	ND	--	<10	--	ND
a+p-Cresol	ND	--	34	--	ND
Di-n-butyl phthalate	ND	--	<10	--	ND
1,2-Dichlorobenzene	ND	--	ND	--	96
1,3-Dichlorobenzene	ND	--	ND	--	< 1.9
1,4-Dichlorobenzene	ND	--	ND	--	284
Aldicarb	ND	--	ND	--	ND
Napthalene	ND	--	147	--	ND
Nitrobenzene	ND	--	ND	--	87
Phenol	ND	--	13	--	ND
1,2,4-Trichlorobenzene	ND	--	ND	--	< 1.9
Pest. & Herb. Compounds					
A-BHC	ND	--	ND	--	ND
G-BHC	ND	--	ND	--	6.0
DAI HPLC Compounds					
Maleic hydrazide	ND	--	ND	--	ND
Nicotine acid	ND	--	ND	--	<900

TABLE 3.3-4 (continued)

Constituents	M2 (6/84)	M6 (4/84)	M6 (6/84)	M12 (4/84)	OW2 (6/84)
Extractable HPLC Compounds					
Benzidine	<25	--	ND	--	<25
3,3'-Dichlorbenzidene	ND	--	ND	--	ND
3.3'-Dimethoxybenzidene	<25	--	ND	--	ND
m-phenylenediamine	<25	--	ND	--	<25
p-phenylenediamine	ND	--	ND	--	<26
Toluene-2,3-Diamine	ND	--	ND	--	<26
Metals & Cyanides					
Aluminum	ND	--	61,500	--	57
Arsenic	ND	50	20	18	99
Barium	20	200	110	<100	17
Beryllium	ND	--	6	--	71
Cadmium	ND	5	<4	<1	<4
Calcium	2800	--	151,000	--	55
Chromium	ND	530	100	<10	70
Copper	ND	--	ND	--	20
Total Cyanide	<25	--	<25	--	<2
Iron	ND	550,000	376,000	46,000	24
Nickel	<20	--	100	--	90
Osmium	<800	--	<800	--	<8
Potassium	590	--	7400	--	40
Sodium	4300	3,273,000	6,940,000	206,000	27
Strontium	ND	--	940	--	41
Thallium	ND	--	<5	--	ND
Vanadium	ND	--	560	--	40
Zinc	10	--	130	--	26

-- not analyzed
ND not detected

TABLE 3.3-5: Tabulation of Carcinogenic Risks*

Constituent	Well Numbers (hypothetical exposure points)				
	M2 (B)	OW1 (C1)	OW2 (A1)	M6 (C2)	M12 (A2)
Benzene	ND	NA	1.2×10^{-3}	1.8×10^{-4}	NA
Chloroform	ND	NA	1.9×10^{-3}	2.8×10^{-4}	NA
Methylene Chloride	ND	NA	1.8×10^{-7}	7.3×10^{-7}	NA
Carbon Tetrachloride	ND	NA	1.1×10^{-3}	ND	NA
Tetrachloroethylene	ND	NA	ND	ND	NA
Arsenic	ND	NA	4.2×10^{-2}	1.5×10^{-2}	7.7×10^{-3}

*Risk measurements based upon average of observed concentrations.

ND - constituent analyzed, but not detected or below detection limits.

NA - not analyzed.

of 1.5 x 10^{-2} while the downgradient well (M-12) has a risk of 7.7 x 10^{-3}.

Systemic toxicants have also been observed in both plumes. The tabulation of hazard indices for these wells is shown in Table 3.3-6. Well OW-2 has a very high concentration of chlorobenzene. This level of contamination relates to a hazard index of 84.2, or more than 80 times the maximum acceptable level. Well M-6 has high levels of toluene, chromium and barium. The total hazard index depends upon the valence state of the chromium. If the chromium is hexavalent, the HI is 28.2, as shown in Table 3.3-6, but if it is trivalent, the HI is 21.1. In either case a toxic risk is posed.

Both plumes pose significant carcinogenic risks, and contain unacceptable levels of systemic toxicants. The plume originating at the manufacturing facility has no compliance point data, but the downgradient well, OW-2, has high levels of arsenic and chlorobenzene. In the plume originating at the hazardous waste management unit, both the compliance point well and the downgradient well would pose significant health risks if used as sources of drinking water. Monitoring has not been done to determine the downgradient extents of these plumes.

A simple analytical model was used to describe contaminant transport toward the river. The model results show that steady state concentrations at 100 feet are reached in one week. Steady state concentrations at the river edge are reached in roughly one year. The steady state concentrations are extremely dependent

TABLE 3.3-6 TABULATION OF HAZARD INDICES FOR SYSTEMIC TOXICANTS

Constituent	Well Numbers (hypothetical exposure points)				
	M2 (B)	OW1 (C1)	OW2 (A1)	M6 (C2)	M12 (A2)
Chlorobenzene	ND	NA	84.2	ND	NA
Methyl Ethyl Ketone	ND	NA	.034	.156	NA
Toluene	ND	NA	.002	.921	NA
1,2 Dichlorobenzene	ND	NA	.021	ND	NA
1,4 Dichlorobenzene	ND	NA	.08	ND	NA
Phenol	ND	NA	ND	.004	NA
Chromium	ND	NA	.93*	7.07*	ND
Nickel	<.06	NA	.257	.286	NA
Barium	1.97	NA	1.67	19.7**	<9.85
Zinc	.001	NA	.004	.018	NA
Total	2.0	NA	87.4	28.2	NA

NA - not available

* Assumed to be hexavalent. Report identifies only total chromium.

** Hazard index based on the higher of the measured values.

upon the dispersivity assumptions. With a dispersivity of 1.0 m, the concentration at the edge of the river is 14.5 percent of that at 100 feet. Because the concentrations of systemic toxicants at points A-1 and C-2 are both over 14.5 times the recommended ADI for some constituents, the ground water at the river edge is likely to exceed ADI for these constituents.

Exposure Assessment

The plumes originating at this facility will discharge into the nearby river. Parts of these plumes will pass outside of the facility property before discharging to the river; however they will pass beneath the property of another chemical manufacturing facility. No supply wells are in the path of the plumes. The river is used as a source of drinking water, though the degree of surface water contamination and the location of drinking water intakes was not provided in the materials reviewed for this case study.

From velocity values for the alluvial aquifer of 14.4 and 4.5 ft/day, it can be approximated that the contamination would have traveled to the river (3600 ft) within a range of 250 days to slightly more than 2 years. This assumes that all the water in the aquifer discharges into the river, thereby preventing underflow. Further analysis of ground-water flow in the area of the river would be necessary in order to adequately characterize its movement.

3.3.3 Case Study D-3

Facility Description

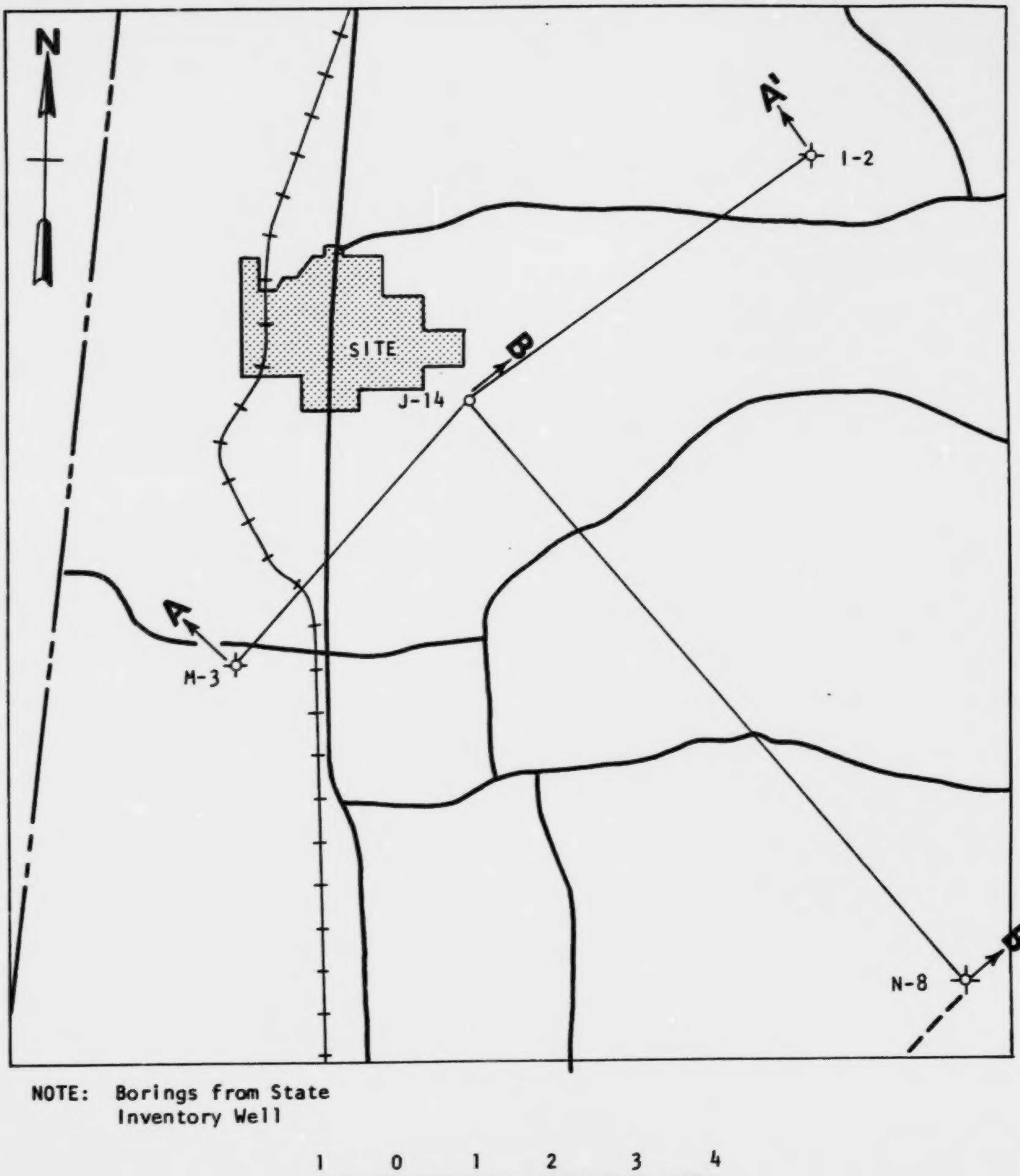
A hazardous waste landfill has been operated at this site since 1977 on approximately 300 acres of the site's 2500 acres (see Figure 2.3-11). Previously, wastes were disposed of in trenches ranging in depth from 30 to 50 feet. Current practice consists of burial of non-liquid containerized and non-containerized wastes in trenches up to 175 feet deep and up to 8 acres in area. It is believed that most listed hazardous wastes have been disposed in this facility.

Climate

Average precipitation in the area is about 50 inches/year. Monthly average precipitation ranges between about 6.2 inches in the winter and spring months to about 2.2 inches in the late summer to early fall. Watersheds in the area are characterized by high amounts of evapotranspiration and widely varying amounts of runoff depending on the surficial geology. Area temperatures are moderate with below freezing temperatures occurring only during short periods. Therefore, accumulations of snow and ice are not a consideration in runoff or water balance calculations.

Regional Hydrogeology

The site is located in the Coastal Plain physiographic province. The rocks in this area generally consist of Upper Cretaceous sediments which dip to the southwest. The facility is located on chalk/marl which is a relatively homogeneous low permeability unit. The chalk was presumably deposited in a clear sea of


N
A'
I-2
SITE
B
J-14
A
M-3
N-8
B'
1 0 1 2 3 4
SCALE IN MILES

NOTE: Borings from State Inventory Well

FIGURE 3.3-11 LOCATION OF DEEP WELL BORINGS AND GEOLOGIC SECTIONS

moderate depths. The uppermost aquifer lies directly beneath the chalk/marl and local ground water is believed to flow east to northeast. The uppermost aquifer is the first stratigraphic unit with the ability to transmit groundwater at a sufficient rate and yield to be used as a water supply.

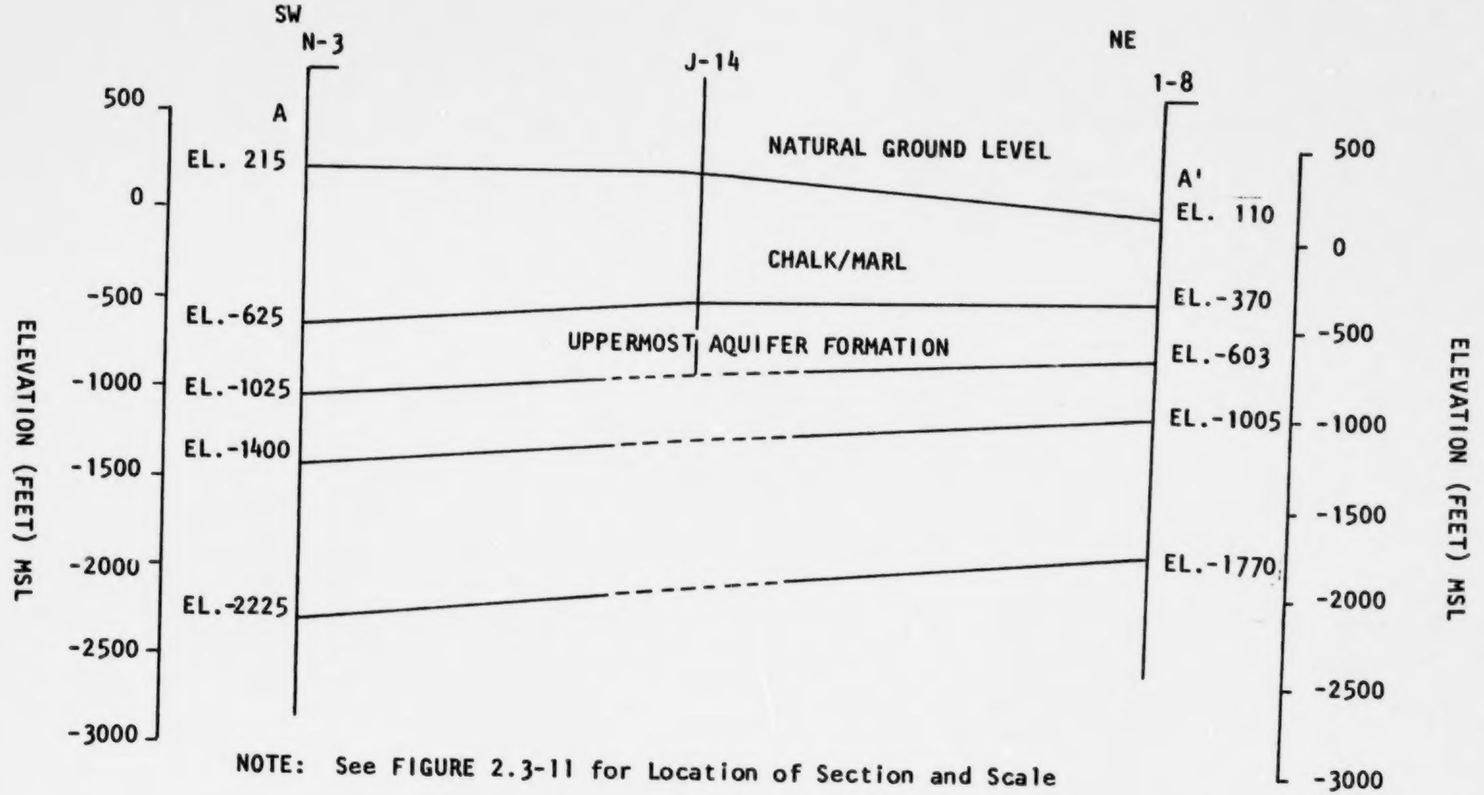
Site Geology

The chalk/marl group (650-750 feet thick) consists of a chalky limestone with a minerologic makeup of 50% calcium carbonate, 44% clay minerals and approximately 6% sand. The lower member of the group is a uniform thin bedded chalky marl with a thickness of approximately 250 feet. The chalk/marl, as previously stated, is reported to be quite homogeneous with very little structure and a low permeability. There is some discussion in the application concerning faulting in the chalk/marl group. The presence of faulting or fractures could greatly effect the migration of contaminants within the chalk/marl group.

The uppermost aquifer formation is approximately 400 feet thick beneath the site and generally consists of thin clay and sand beds with thick and coarse sand and gravel beds at its base. This formation is divided into three units with the upper 100 feet being a sand member. Figures 3.3-12 and 3.3-13 represent schematic sections in the area of the site.

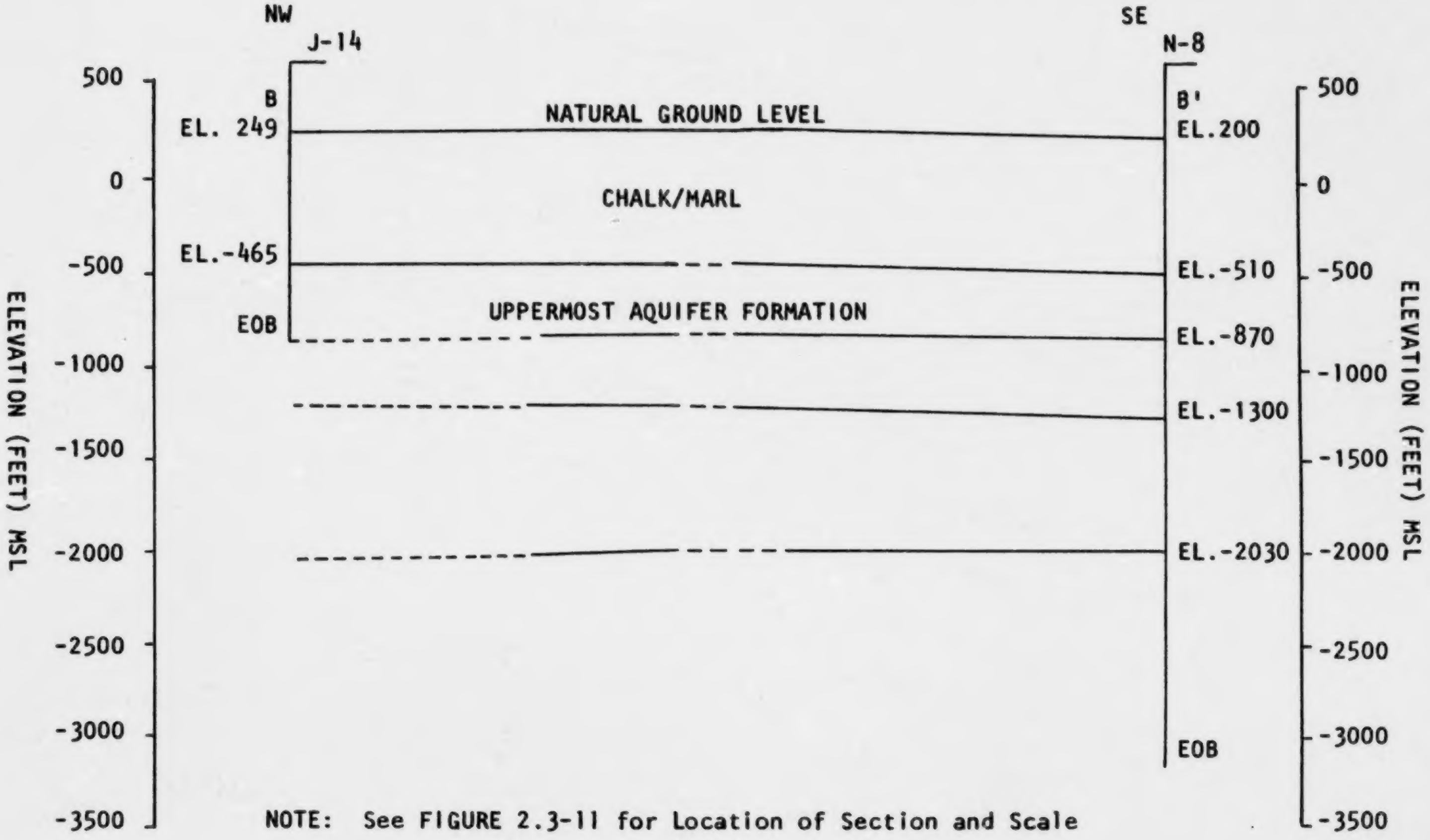
Site Hydrology

The potentiometric surface of the chalk/marl is generally 10 to 30 feet below the ground surface. However, because evaporation is greater than precipitation, dry trenches have been excavated to over 100 feet. From water level measurements in the uppermost


SW
N-3
A
EL. 215
EL.-625
EL.-1025
EL.-1400
EL.-2225
J-14
NE
1-8
A'
EL. 110
EL.-370
EL.-603
EL.-1005
EL.-1770
NATURAL GROUND LEVEL
CHALK/MARL
UPPERMOST AQUIFER FORMATION
500
0
-500
-1000
-1500
-2000
-2500
-3000
ELEVATION (FEET) MSL

NOTE: See FIGURE 2.3-11 for Location of Section and Scale

FIGURE 3.3-12 GEOLOGIC SECTION A-A' NORMAL TO STRIKE


NW
SE
J-14
N-8
B
B'
EL. 249
EL.200
NATURAL GROUND LEVEL
CHALK/MARL
EL.-465
EL.-510
UPPERMOST AQUIFER FORMATION
EOB
EL.-870
EL.-1300
EL.-2030
EOB
500
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
ELEVATION (FEET) MSL
ELEVATION (FEET) MSL

NOTE: See FIGURE 2.3-11 for Location of Section and Scale

FIGURE 3.3-13 GEOLOGIC SECTION B-B'
PARALLEL TO STRIKE

aquifer, a downward gradient into the aquifer was observed from the chalk/marl in the eastern portion of the site. In the western portion of the site, however, an upward gradient from the uppermost aquifer into the chalk/marl was observed. Head differences reach a maximum of 80 feet in the eastern portions of the site and a maximum of 20 feet in the site western portions. Although the application states that vertical gradients do exist (approximately .11) and ground-water movement occurs, the actual movement is believed to be negligible. Field permeability values are reported to range from 5.7 x 10^{-8} to 1 x 10^{-7} cm/sec. Also, a laboratory determined effective porosity of 33.4% was reported.

Plume Information

There was no information available concerning existing monitoring well locations, nor were any monitoring data presented. However, considering the low permeability values and thickness of the chalk/marl, migration into the uppermost aquifer may be unlikely except over extremely long time periods. This statement appears true even though much of the actual waste disposal occurs below the water table in the chalk/marl unit.

There is some discussion in the application regarding proposed monitoring well installations in the chalk/marl. Sixteen core holes will be placed around the unlined trenches used during interim status. These core holes will be completed as wells screened across selected fractures in the chalk. An additional 18 wells will be screened below the base of adjacent trenches. This shallow monitoring system will encircle the landfill trenches. Two background wells away from active landfilling will also be installed to depths of 100 feet.

Time of Travel

Using the following application-supplied values, a vertically downward ground-water velocity was calculated. (K values were obtained from packer and well recovery tests).

Hydraulic Conductivity (K)	1×10^{-7} cm/sec
Hydraulic Gradient (i)	.11
Effective Porosity (n_e)	.33
Ground Water Velocity ($\overline{V}$)	.034 ft/yr

From a ground water velocity of .034 ft/yr a TOT_{100} of approximately 3000 years can be expected. There is 550 feet between the uppermost aquifer and the base of the waste management unit at the site. Considering the previously listed velocity, the contamination would take approximately 16,200 years to reach the uppermost aquifer.

Health Risk Assessment

The contaminant plume at this facility is hypothetical. The simulation model assumed a steady state source release rate of 1.0 g/yr of benzene from a point at the facility. The resulting concentrations and hypothetical health risks are shown in Table 2.3-8 at distances of 100 feet and 550 feet. At 100 feet, the plume reaches steady state after 7500 years with a concentration of 0.805 ppb and a hypothetical carcinogenic risk of 1.1×10^{-5}. At 550 feet, the plume reaches steady state after 33,000 years with a concentration of 0.87 ppb and a risk of 1.24×10^{-6}.

The health risk indicated in this table is the hypothetical risk associated with the small 1.0 g/yr assumption. At 1×10^{-6}, the steady state risk is approximately at the threshold of acceptability at both 100 and 550 feet.

Table 3.3-7: Results of Benzene Plume Simulation

Time (years)	Benzene Concentration (ppb)		Health Risk
	100 ft	550 ft	
500	0		0
1000	3.72 x 10-3		5.3 x 10-9
5000	6.33 x 10-1		9.0 x 10-7
7500	8.05 x 10-1		1.15 x 10-6
8000		6.58 x 10-5	9.4 x 10-11
10,000		1.04 x 10-2	1.49 x 10-8
15,000		1.68 x 10-1	2.4 x 10-7
20,000		5.74 x 10-1	8.2 x 10-7
30,000		8.61 x 10-1	1.23 x 10-6
33,000		8.68 x 10-1	1.24 x 10-6

Exposure Assessment

Based on available information, there is no plume at this facility. If one does develop, it will not pose much of a risk because the hydraulic conductivity of the chalk/marl is so low that it would take an extremely long time for exposure to occur. Such a plume would travel very slowly, on the order of one foot in 300 years and would not be expected to reach the uppermost aquifer for over 15,000 years. Furthermore, the chalk/marl formation is not pumped for any domestic, commercial, or agricultural purposes.

3.3.4 Case Study D-4

Facility Description

A plume of ground water contaminated by liquid metal-plating effluent has formed downgradient from an industrial park on Long Island, New York. Discharges from the plant to the shallow aquifer began in the 1940s. Waste water treatment was installed in 1958, and the operations ceased in 1970. While the facility was in operation the plume contained elevated chromium and cadmium concentrations extending approximately 4,300 feet downgradient from the waste disposal basins and discharged into a small creek.

Hydrology

The area is underlain by the upper glacial (water table) aquifer, and the Magothy aquifer, which supplies all the drinking water to the area. The aquifer of concern is the upper glacial aquifer which, in the study area, ranges from 80 to 140 feet thick. The water table in the area ranges from 0 to 25 feet below land surface. This aquifer consists chiefly of medium to coarse sand with lenses of fine sand and gravel. Locally, beneath and immediately west of the stream, the rate of movement of the leading edge of the plume may be as low as 0.5 feet/day, owing to the smaller hydraulic gradient in that area. The TOT for 100 feet is therefore less than 200 days.

Plume Information

Maximum concentrations of hexavalent chromium determined during successive investigations ranged from 40 mg/l in 1949 to 10 mg/l in 1962. Cadmium concentrations ranged from 0.01 to 10 mg/l, but in most places, were less than 1 mg/l. Maximum observed concentrations of cadmium and chromium in the creek were 0.1 and 2.9 mg/l, respectively. Concentrations of both cadmium and hexavalent chromium in most of the plume and in part of the the creek exceeded the limits of 0.01 and 0.05 mg/l, respectively, as stated in the National Interim Primary Drinking Water Standards.

The location of the monitoring wells is depicted in Figure 3.3-14. No background well was available. Point D, the leading edge of the plume, is interpreted as Well #62. Well #2 was chosen as point A, even though it lies 700 feet along the flow line. No monitoring well was installed at compliance point C.

Analysis of the single samples taken in the fall of 1975 from the observation wells at the site are reported in Table 3.3-8. Well #2, the closest well to the disposal basins, showed the highest concentration of contaminants. Figure 3.3-15 presents a cross-section of the area and the plume, along the axis of flow toward the creek.

Health Risk Assessment

The concentrations of the constituents used in the following assessments may not represent the largest values passing through the hypothetical exposure points, because ground-water quality sampling has occurred between 10 and 20 years after waste water treatment operations had reduced the concentrations of hazardous constituents entering the ground water.

No oral carcinogens were identified at this site. Cadmium and chromium VI have been identified as inhalation carcinogens, but no oral carcinogenic risks have been demonstrated. Cadmium, chromium VI and chromium III are all recognized as systemic

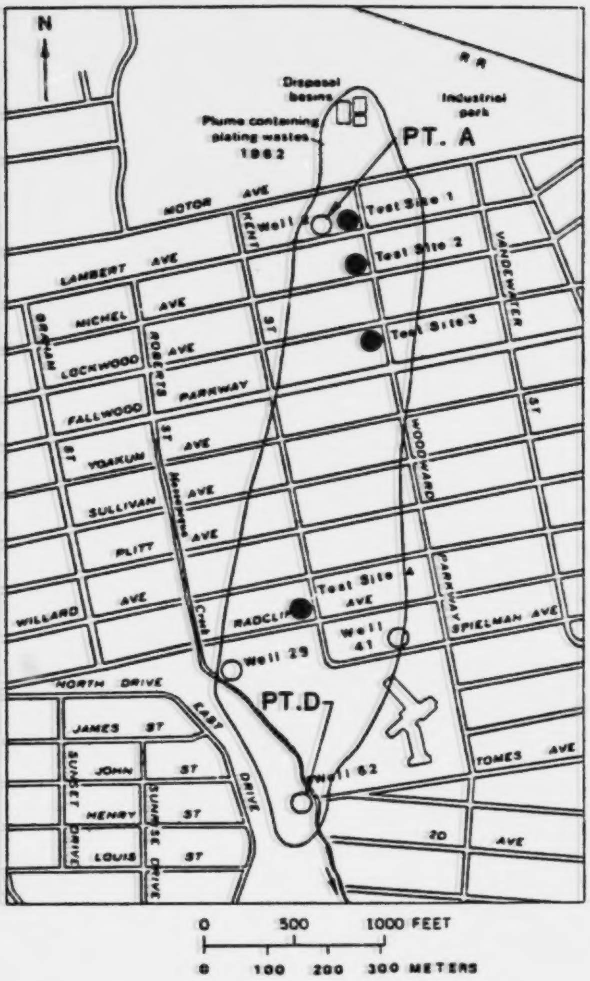
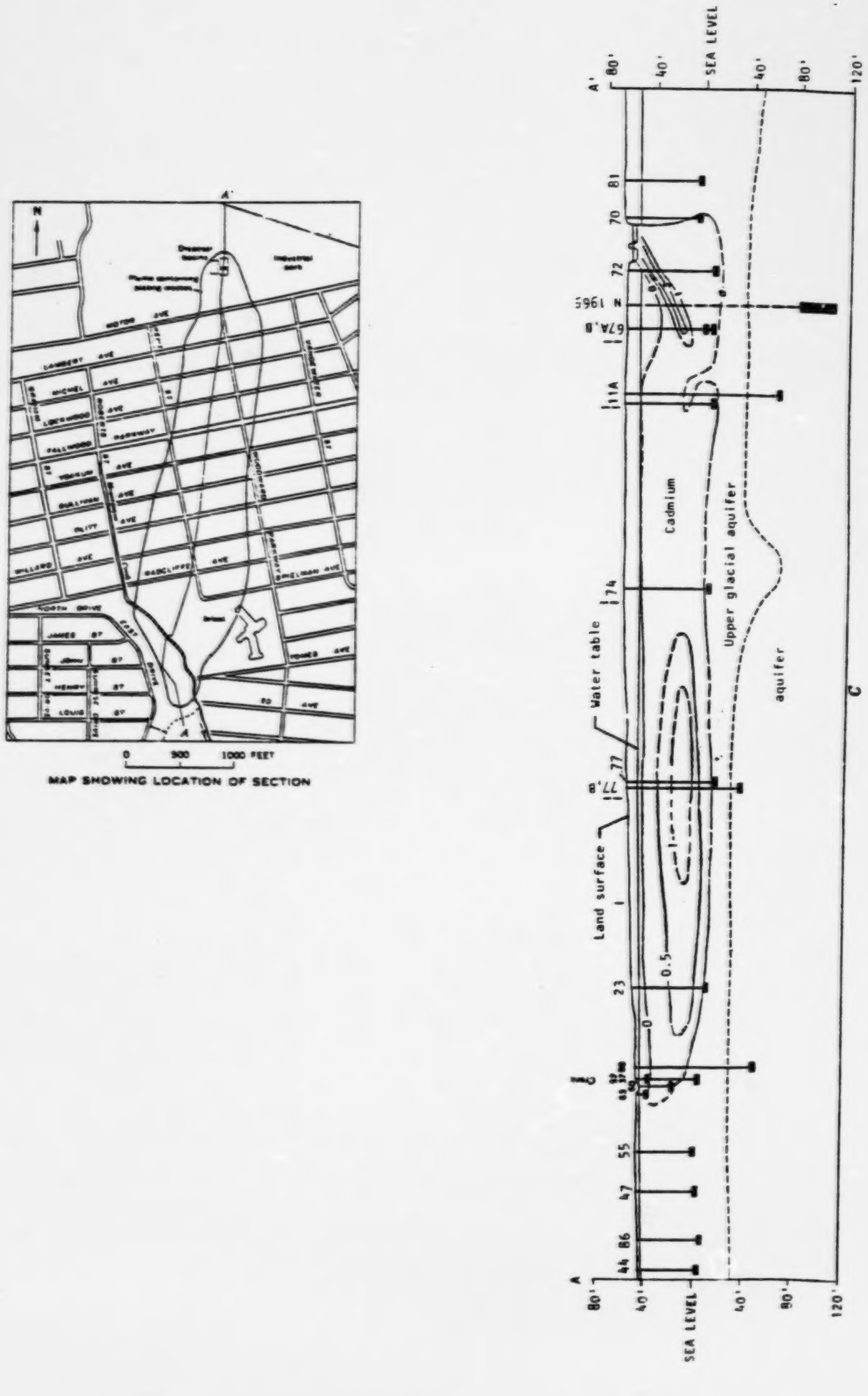

N
R R
Disposal basins
Industrial park
Plume containing plating wastes 1962
PT. A
MOTOR AVE
KENT
Well 4
Test Site 1
Test Site 2
Test Site 3
Test Site 4
VANDEWATER
LAMBERT AVE
MICHEL AVE
GRAHAM
ST
ROBERTS
LOCKWOOD AVE
PARKWAY
FALLWOOD
ST
ST
YOAKUM AVE
ST
WOODWARD
SULLIVAN AVE
PLITT AVE
WILLARD AVE
Creek
RADCLIFF AVE
PARKWAY
SPIELMAN AVE
Well 41
Well 29
NORTH DRIVE
EAST DRIVE
PT.D
JAMES ST
JOHN ST
HENRY ST
LOUIS ST
SUNSET DRIVE
SUNRISE DRIVE
Well 62
TOMES AVE
20 AVE
0
500
1000 FEET
0
100
200
300 METERS

FIGURE 3.3-14 WELL PATTERNS AND PLUME OUTLINE

Table 3.3-8: CONCENTRATION OF METALS IN MONITORING WELLS (ppb)

Compound	Point D (Well #62)	Point A (Well #2)[a]
Trivalent chromium	110	366
Hexavalent chromium	0	24
Cadmium	440	6,900

[a] Well #2 is located approximately 700 feet from the disposal basins.



N
A'
A
Industrial park
LAMBERT AVE
MICHEL AVE
LOCKWOOD AVE
FALLWOOD PARKWAY
SULLIVAN AVE
OLITT AVE
WILLARD AVE
RADCLIFFE AVE
NORTH DRIVE
JAMES ST
JOHN ST
HENRY ST
LOUIS ST
0 500 1000 FEET
MAP SHOWING LOCATION OF SECTION
80'
40'
SEA LEVEL
40'
80'
120'
44
86
47
55
23
1
77
77,B
74
11A
67A,B
N 1965
72
70
81
Land surface
Water table
Cadmium
Upper glacial aquifer
aquifer
C
0
0.5
1

FIGURE 3.3-15 CROSS-SECTION OF GROUND-WATER PLUME

toxicants on EPA's listing of ADI's. The remaining constituents appearing at elevated concentrations (iron, manganese and zinc) are neither carcinogenic nor recognized systemic toxicants.

The hazard indices for cadmium and chromium are presented in Table 3.3-9. This table shows that the concentrations of cadmium represent a significant toxic hazard, because ingestion of 2 litres per day of water at the contamination levels observed at points A or D represents a cadmium ingestion of many times the ADI. The hazard index for point D is 25. Neither hexavalent nor trivalent chromium concentrations have hazard indices in excess of 1.0.

Exposure Assessment

Prior to discovery of the contaminant plume in the early 1940's, the shallow aquifer was widely used as a source of drinking water. The yield probably exceeds 10 gallons per minute in nearby shallow local wells. In addition, the contaminated portion of this aquifer underlies an area of approximately 77 acres. The leading edge of the plume appears to be influenced by the position of the creek, although Figure 3.3-15 suggests that part of the plume may flow under and beyond the Creek.

Use of this contaminated ground water for drinking purposes does not appear to occur because the many residences overlying the plume are served by municipal water. If the area were not urbanized, there would be a greater chance that the ground water would be used for drinking purposes. Also, because the plume is well documented, potential users would likely be warned by local authorities to avoid consuming this ground water.

Table 3.3-9: Tabulation of Hazard Indices

Constituent	ADI (mg/kg/day)	Exposure (mg/kg/day) A	Exposure (mg/kg/day) D	Hazard Index A	Hazard Index D
Cadmium	.0005	0.197	0.0126	394	25.2
Chromium III	1.60	.0105	.0031	.0066	.0019
Chromium VI	.0021	.0007	0	.33	0
Total	---	---	---	394	25.2

Conclusions

The cadmium concentration at points A and D represent significant toxic risk if they are ingested in drinking water. The exposures that would result from drinking water use exceed acceptable daily intake thresholds by a factor of 394 at point A and a factor of 25 at point D.

This case demonstrates that a large-scale plume can develop within a hydrogeologic setting that fails the TOT_{100} criterion. The potential for exposure to this plume is high because the plume occupies a large portion of an aquifer that has a large sustained yield. An opportunity for large-scale, direct exposure to this plume appears to be prevented only by the highly urban character of this area. Were the site more rural in character, significant use of the ground water would be expected. Impact on stream quality has not been assessed in this case study.

3.3.5 Case Study D-5

Facility Description

This case study concerns ground-water contamination associated with several unlined surface impoundments containing creosote wastes in Florida. The site began operation in 1902; operations ceased around 1981. Figure 3.3-16 shows the locations of the facility and the monitoring wells used in this assessment. Figure 3.3-17 is a hydrogeologic cross-section of the site. As shown by monitoring data, the plume extends approximately 1,000 feet from the impoundments towards a bay. The plume length for phenols is considerably less than anticipated by theoretical calculations. [Such calculations project the phenol plume to have migrated 4 to 5 kilometers downgradient from the site beneath the bay.] However, there are no apparent monitoring wells beyond 300 meters south of the site that verify these calculations. Although many of the expected waste components are absent or extremely dilute near the bay, a dark sludge band has been observed on the beach at low tide. This suggests transport to the bay through the ground-water system.

Hydrogeology

The site overlies an upper sand and gravel aquifer that is approximately 90 meters thick at the site area. The water table is within 1.2 meters of the land's surface near the impoundments. Contamination has been found only within the upper 30 meters of the aquifer, due probably to the retarding influence of the silt/clay lens shown in the cross-section at a depth of approximately 10 feet. TOT_{100} is estimated to be 25 days.

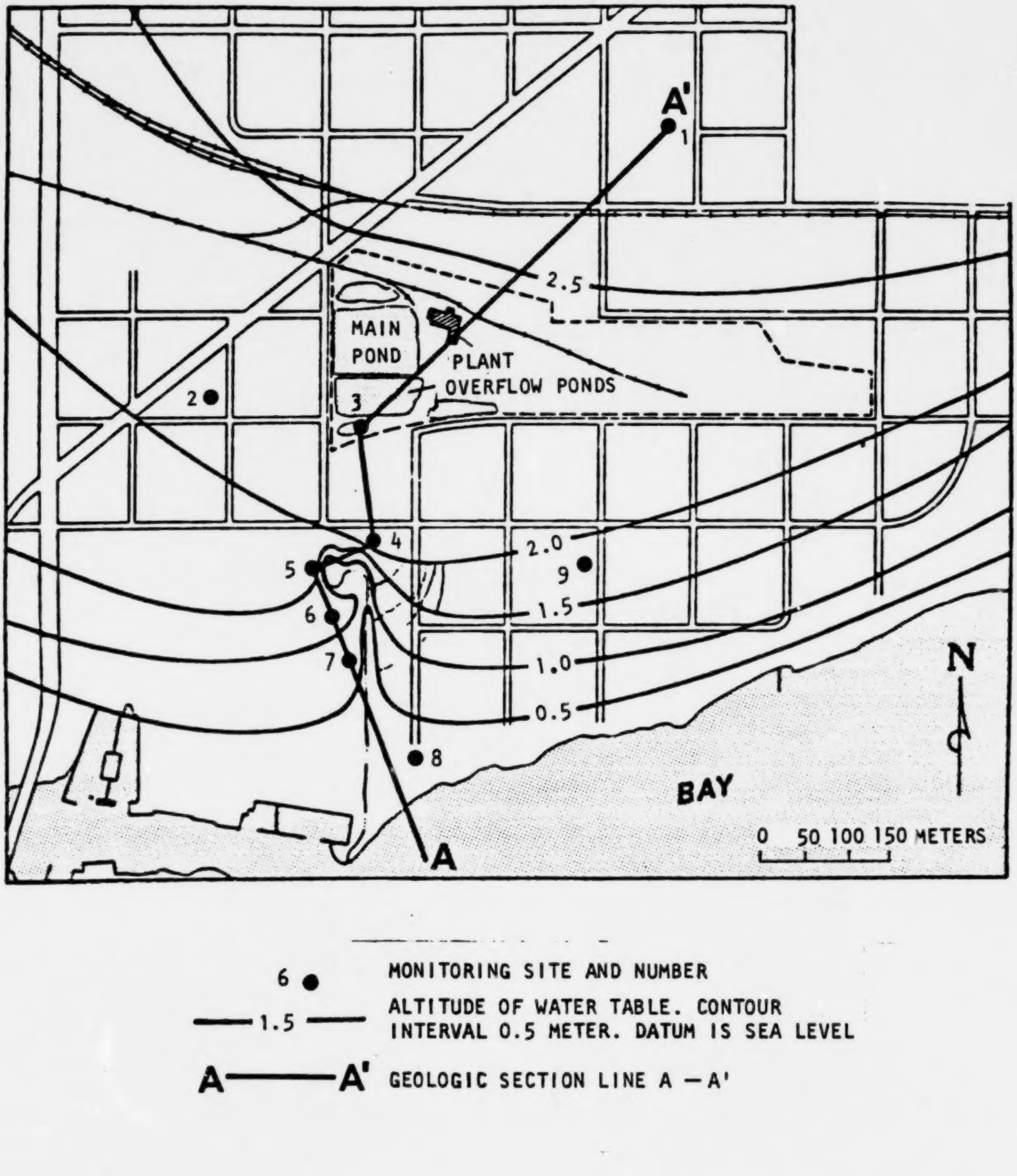
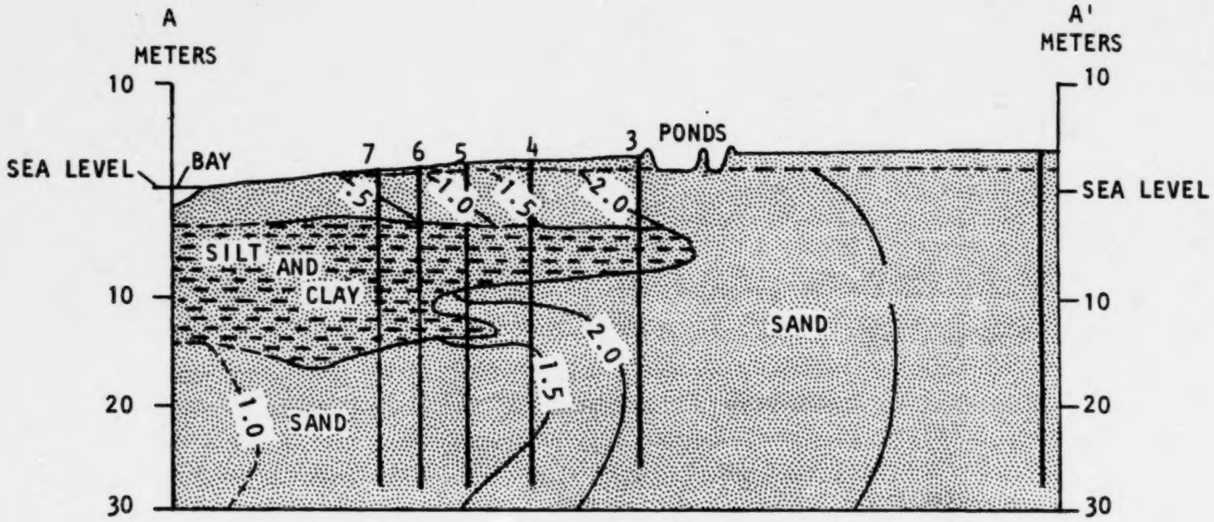

A'
1
2.5
MAIN POND
PLANT
OVERFLOW PONDS
2
3
4
5
2.0
9
6
1.5
7
1.0
N
0.5
8
BAY
0 50 100 150 METERS
A
6 ● MONITORING SITE AND NUMBER
—— 1.5 —— ALTITUDE OF WATER TABLE. CONTOUR INTERVAL 0.5 METER. DATUM IS SEA LEVEL
A——A' GEOLOGIC SECTION LINE A — A'

FIGURE 3.3-16 LOCATION OF MONITORING SITES (WELLS)

FIGURE 3.3-17 HYDROGEOLOGIC CROSS-SECTION OF SITE
(January 1984)


A
METERS
10
SEA LEVEL
BAY
7
6
5
4
3
PONDS
A'
METERS
10
SEA LEVEL
.5
1.0
1.5
2.0
SILT
AND
CLAY
10
10
SAND
2.0
1.5
20
1.0
SAND
20
30
30

GENERALIZED SECTION. NOT TO SCALE

4 MULTIPLE DEPTH WELL SITE

---2.0—— ALTITUDE OF POTENTIOMETRIC SURFACE. CONTOUR INTERVAL 0.5 METER. DATUM IS SEA LEVEL. DASHED WHERE APPROXIMATE

Plume Information

Monitoring data are available for 33 chemicals falling into five groups. These groups are: phenols, polycyclic aromatic hydrocarbons, nitrogen heterocyclics, sulfur heterocyclics, and oxygen heterocyclics. These data are presented for six well locations in Table 3.3-10. For the purpose of this analysis, well 1 is designated as point B, well 3 as point C (compliance), well 4 as point A (although it lies some 250 feet from the compliance point) and well 7 as point D, the downstream edge of the plume. The location of these wells is shown in Figure 3.3-20.

Health Risk Assessment

These monitoring data are analyzed for adverse health risks to hypothetical users in accordance with established toxicity factors for carcinogens and systemic toxicants, and by analogy with constituents with unknown toxicities to similar constituents with known toxicities. The latter method is used here because extremely high levels of a compound are present for which no toxicity values are available.

1. Standard procedure

   a. Carcinogens

      Of the constituents listed in Table 2.3-10, only Benzo-(a)-pyrene is known to be carcinogenic, and it was not detected at any of the wells.

   b. Toxicants

      Several of the constituents have known toxic risks, and include: phenol, biphenyl, pentachlorophenol, and fluoranthene. The estimated Hazard Index for each of these is as follows:

TABLE 3.3-10 CHEMICAL ANALYSES FOR SELECTED ORGANIC CONTAMINANTS IN GROUND WATER AT A DEPTH OF 18.3 METERS AT SITES 1 AND 3 THROUGH 7*

	Well numbers/hypothetical exposure points					
	1	3	4	5	6	7
Compound	B	C	A			D
Phenols						
Phenol	ND	13.3	ND	ND	ND	ND
2-methylphenol	ND	456	7.8	15.9	44.7	2.3
2,4-dimethylphenol	ND	1,835	623	83	178	405
3,5-dimethylphenol	ND	1,666	548	13.5	999	6.6
2,3,5-trimethylphenol	ND	317	36.5	35.9	218.8	60.9
1-naphthol	ND	360	ND	111	216	138
2-naphthol	ND	317	ND	2.4	13.3	81.1
Pentachlorophenol	ND	11.6	ND	ND	ND	ND
Total phenols	ND	4,976	1,215	262	1,770	694
Polycyclic aromatic hydrocarbons						
Indane	ND	19.0	ND	54.7	435	186
Naphthalene	ND	1,976	27.3	1,038	271	1,072
2-methylnaphthalene	ND	159	1.1	87.3	437	156
1-methylnaphthalene	ND	91.1	0.5	44.7	260	81.3
Biphenyl	ND	22.0	--	7.8	53.2	15.4
Acenaphthene	ND	157	1.2	44.9	246	75.9
Fluorene	ND	82.1	1.2	17.3	103.4	34.5
Phenanthrene	ND	57.2	1.6	2.9	49.4	12.5
Anthracene	ND	3.2	ND	ND	3.0	ND
Fluoranthene	ND	2.8	0.2	ND	ND	ND
Pyrene	ND	1.6	0.2	ND	ND	ND
Benzo(a)pyrene	ND	ND	ND	ND	ND	ND
Total polycyclic aromatic hydrocarbons	ND	2,571	33	1,298	1,858	1,634
Nitrogen heterocycles						
2,4-dimethylpyridine	ND	ND	ND	ND	ND	ND
Quinoline	ND	3.5	ND	ND	ND	ND
2-methlyquinoline	ND	ND	ND	ND	2.7	ND
2-quinolinone	ND	1,217	125	214	517	94
Acridine	ND	1.0	ND	ND	ND	ND
Carbazole	ND	339	13.5	52.5	299	104
Acridinone	ND	12.4	ND	2.2	11.4	2.4
Total nitrogen heterocycles	ND	1,573	139	269	830	200

* Concentrations in micrograms per liter; ND, not detected.

TABLE 3.3-10 CHEMICAL ANALYSES FOR SELECTED ORGANIC CONTAMINANTS IN GROUND WATER AT A DEPTH OF 18.3 METERS AT SITES 1 AND 3 THROUGH 7 (Continued)*

	Well numbers/hypothetical exposure points					
	1	3	4	5	6	7
Compound	B	C	A			D
Sulfur heterocycles						
Benzo(b)thiophene	ND	268	6.0	82.7	442	157
Dibenzothiophene	ND	3.6	0.5	4.9	4.4	1.1
Total sulfur heterocycles	ND	272	7	88	446	158
Oxygen heterocycles						
Dibenzofuran	ND	89.3	0.5	15.1	101.1	31.1
Total oxygen heterocycles	ND	89	1	15	101	31

* Concentrations in micrograms per liter; ND, not detected

	A	B	C	D
Biphenyl	ND	ND	.013	.009
Phenol	ND	ND	.004	ND
PCP	ND	ND	.011	ND
Fluoranthene	.006	ND	.013	ND
Total Hazard Index	.009	ND	.25	.12

ND - not detected

2. Estimation of unknown toxicities by analogy

Extremely high concentrations of 2,4-dimethylphenol, 3,5-dimethylphenol, and 2,3,5-trimethylphenol have been observed at this site, but these compounds do not have assigned EPA toxicity values. EPA does, however, list ADIs for 2,6-dimethylphenol and 3,4-dimethylphenol of 0.00019 and 0.00044 mg/kg/day, respectively. We have chosen the lower of the two, 0.00019, as a conservative estimate of the ADI for 2,4-di, 3,5-di, and 2,3,5-trimethylphenol.

	A	B	C	D
Total Concentration (mg/l)	1.20	ND	3.83	0.47
Hazard Index	185	ND	588	72.3

Exposure Assessment

The potential for exposure to contaminants at this site could be great due to the potentially high yield of the aquifer as shown by nearby production wells (e.g., 5,500 gallons per minute) and the areal extent of the plume (approximately 7.4 acres). There is, however, no present indication that ground water in the area of the plume is being used for drinking water purposes. A study is underway to determine if there have been any detrimental environmental effects to the bay.

Conclusions

The evidence of significant toxic risk at this site is convincing, although the substances of concern are not explicitly represented on the ADI list for systemic toxicants. The EPA list of ADIs shows 2,6-dimethylphenol to be one of the most toxic substances on that list, with an ADI of 0.00019 mg/kg/day. Application of this toxicity threshold to chemically similar 2,4-dimethylphenol, 3,5-dimethylphenol and 2,3,5-trimethylphenol observed at this site is a reasonable procedure, though it is conservative and may tend to overestimate risk. However, the concentrations at this site are so high that even an ADI of 0.0019 mg/kg/day (i.e., 100 times less toxic than 2,6-dimethylphenol) would show significant risks.

The ground water characterized by this risk extends for a substantial distance from the site (approximately 1,000 feet). The opportunity for exposure is high; the sustained yield of the geologic unit containing the plume can exceed 5,500 gpm. The site clearly fails the proposed TOT_{100} criterion.

3.3.6 Case Study D-6

Facility Description

A facility which handled hazardous wastes is located at a former sand and gravel pit operation. The facility's operations have resulted in the release of hazardous constituents to the ground water beneath the site. The facility currently consists of a fenced enclosure with an incinerator, a concrete block building, and an asphalt lined lagoon (see Figure 3.3-24). Outside of the fenced enclosure is an undeveloped area partially enclosed by second fence constructed to restrict vehicular access. Prior to 1972 the site was a sand and gravel pit, which was allegedly used to store and dispose of contaminated by-products from tank cleaning.

The on-site asphalt lagoon was originally constructed in 1972 to accommodate waste generated by a marine oil spill of 100,000 gallons of industrial fuel. The existing incinerator was also upgraded at that time. In addition to the oil spill wastes, the owner also accepted tank bottoms of number 6 and number 4 oil, septic tank wastes, and industrial process wastes. Approximately 100,000 to 200,000 gallons were received annually by the facility between 1972 and 1977.

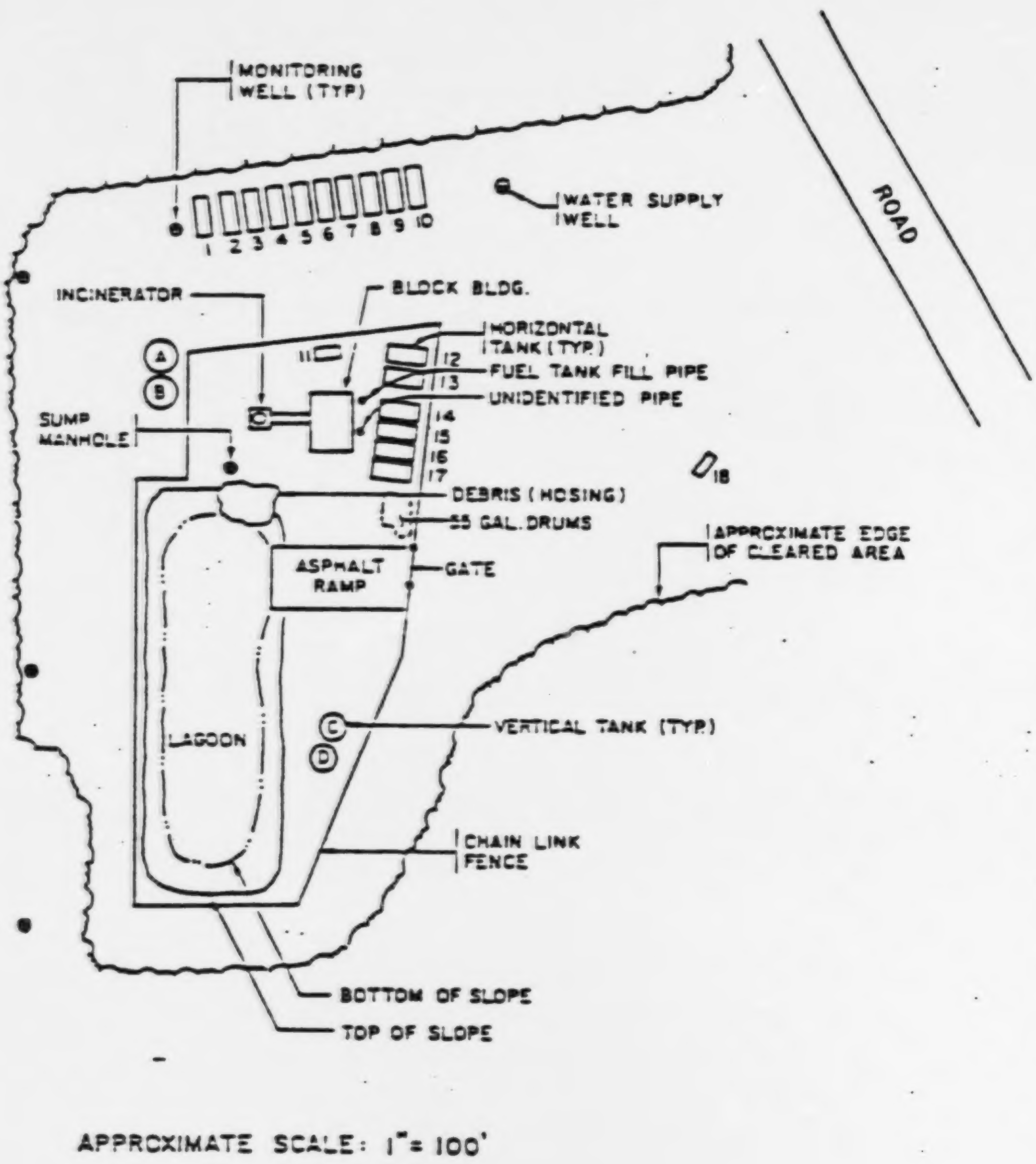
The facility was operated as a transfer station for the wastes listed above. Initially, the incinerator with afterburners and pollution control equipment was used to dispose of oil impregnated refuse (seaweed from the oil spill, rags, etc.). However, the incinerator was not used after 1975. The typical method of operation was to accumulate wastes in large tanks until sufficient quantities were obtained for shipment to refiners or off-site disposal. Contents of the lagoon were then transferred to the large tanks. Subsequently, the tanks leaked. Also, numerous accounts allege that rinse waste and oily wastes were applied directly to the ground surface. The area between the inner fenced area and the adjacent road was once allegedly used for dumping and burning and contains buried drums. This area has since been filled to grade by the site owner.

Environmental Setting

The topopgraphy of the site is relatively flat west of the adjacent road with the fenced enclosure and the areas to the west and north lying in a excavated area. Off-site, the land slopes steeply eastward to the river. Elevations range from approximately 300 feet mean sea level (MSL) at the site to less than 200 feet MSL at the river, approximately 3/4 mile due east.

Site area surface and groundwater discharge to the river and its tributary brook. The State's department of environmental protection has classifed the river as B-2, acceptable for recreation, including water contact. Class B-2 waters may also be used for industrial and potable supply after treatment.

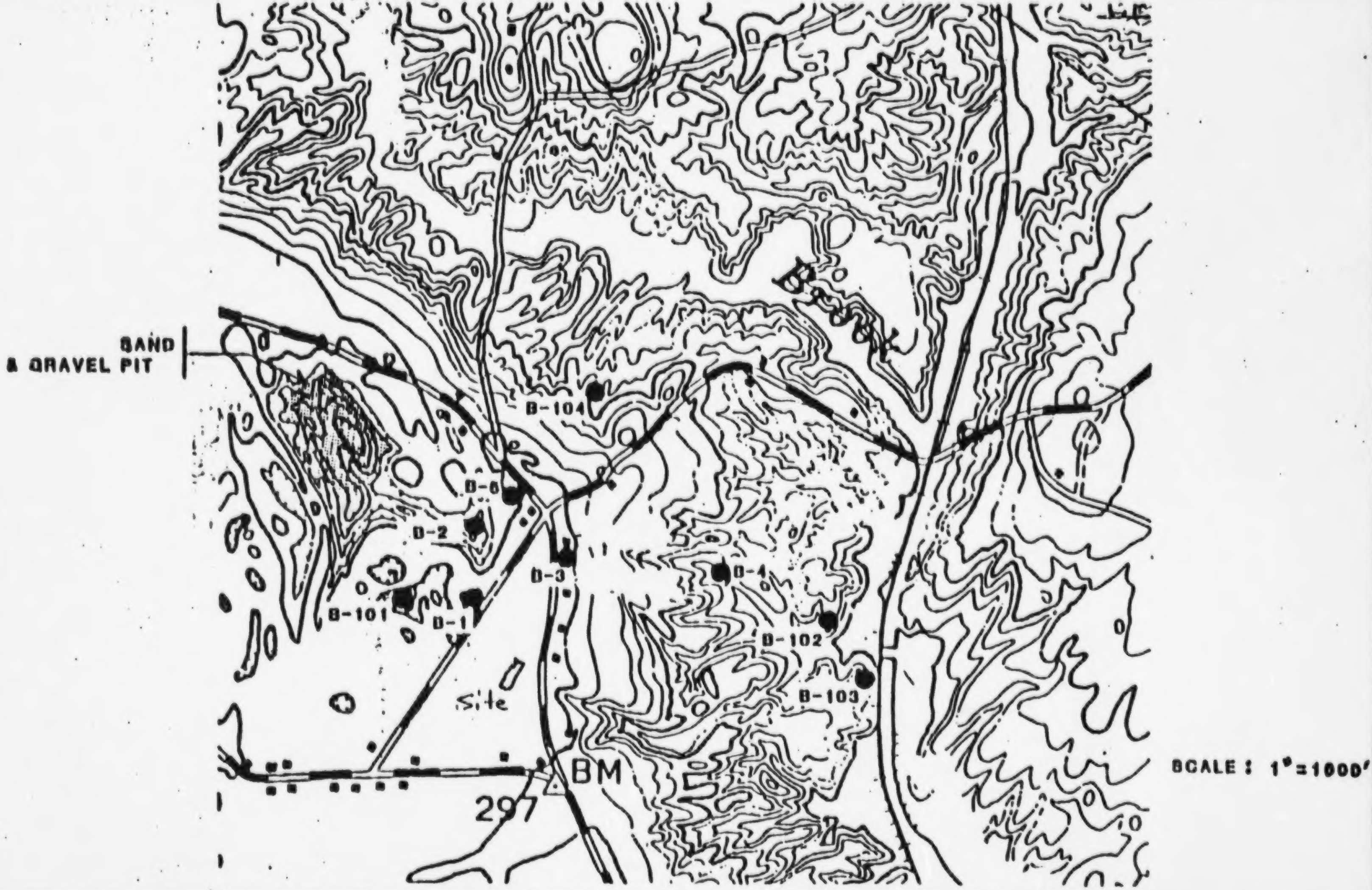
Site surface drainage is contained on-site and the water either evapotranspirates or percolates into the soil. The percolation rates through the contaminated soils at the site are likely to be approximately twice as high as usual for the state, creating little or no run-off.


MONITORING WELL (TYP)
1 2 3 4 5 6 7 8 9 10
WATER SUPPLY WELL
ROAD
INCINERATOR
BLOCK BLDG.
HORIZONTAL TANK (TYP)
A
B
11
12
13
14
15
16
17
FUEL TANK FILL PIPE
UNIDENTIFIED PIPE
SUMP MANHOLE
18
DEBRIS (HOSING)
55 GAL. DRUMS
APPROXIMATE EDGE OF CLEARED AREA
ASPHALT RAMP
GATE
LAGOON
C
D
VERTICAL TANK (TYP)
CHAIN LINK FENCE
BOTTOM OF SLOPE
TOP OF SLOPE
APPROXIMATE SCALE: 1" = 100'

SITE PLAN

N TRUE

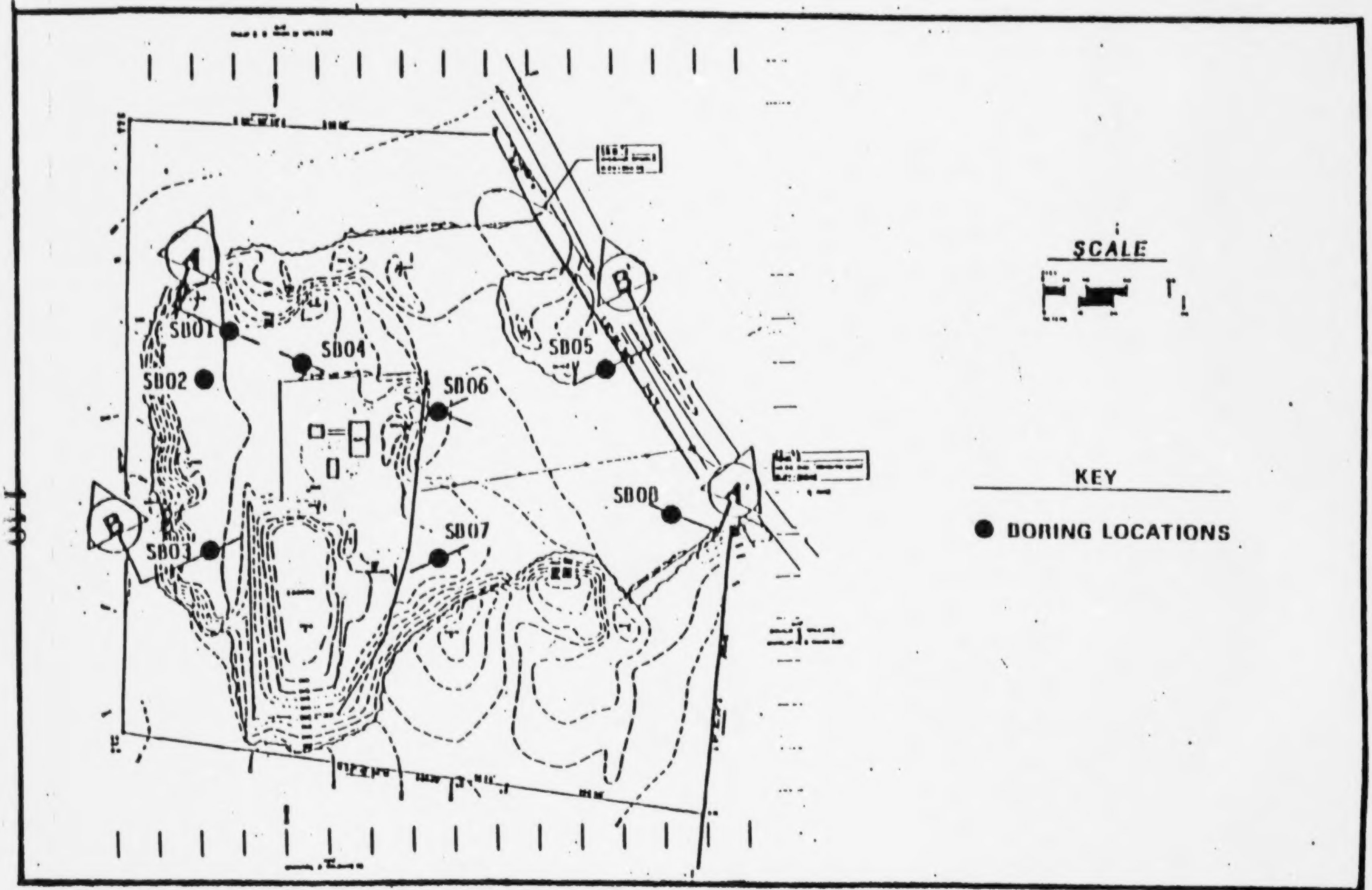
FIGURE 3.3-18


SAND
& GRAVEL PIT
Brook
B-104
D-6
D-2
D-3
D-4
B-101
D-1
B-102
B-103
Site
BM
297
SCALE : 1"=1000'

LOCATIONS OF OFF-SITE MONITORING WELLS
(BASE MAP FROM USGS QUADRANGLE)

N

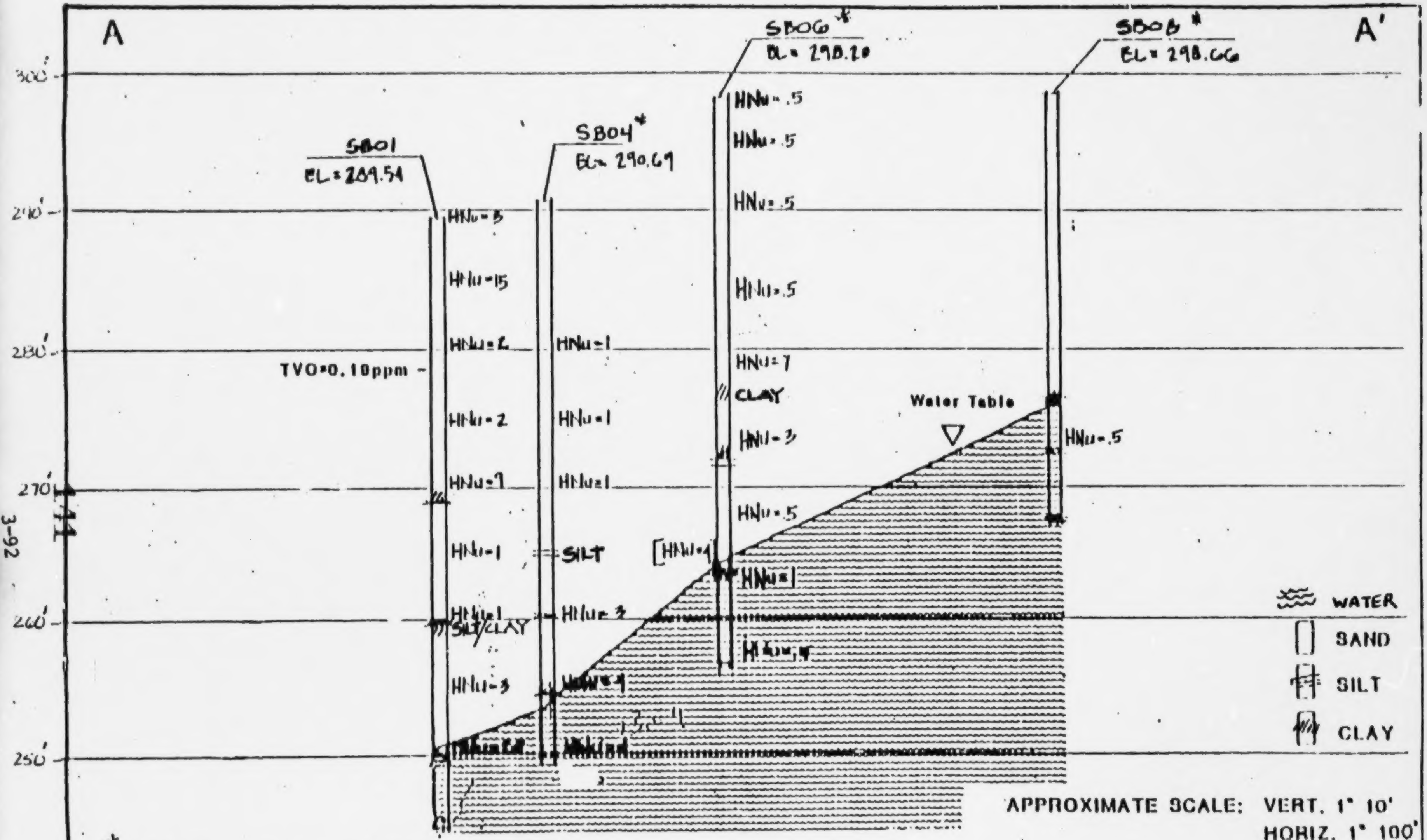
FIGURE 3.3-19


SD01
SD02
SD03
SD04
SD05
SD06
SD07
SD00
A
B
SCALE
KEY
● BORING LOCATIONS

ON-SITE SUB SURFACE SOIL BORING LOCATIONS AND LOCATIONS OF SITE SOIL SECTIONS

N TRUE

FIGURE 3.3-20



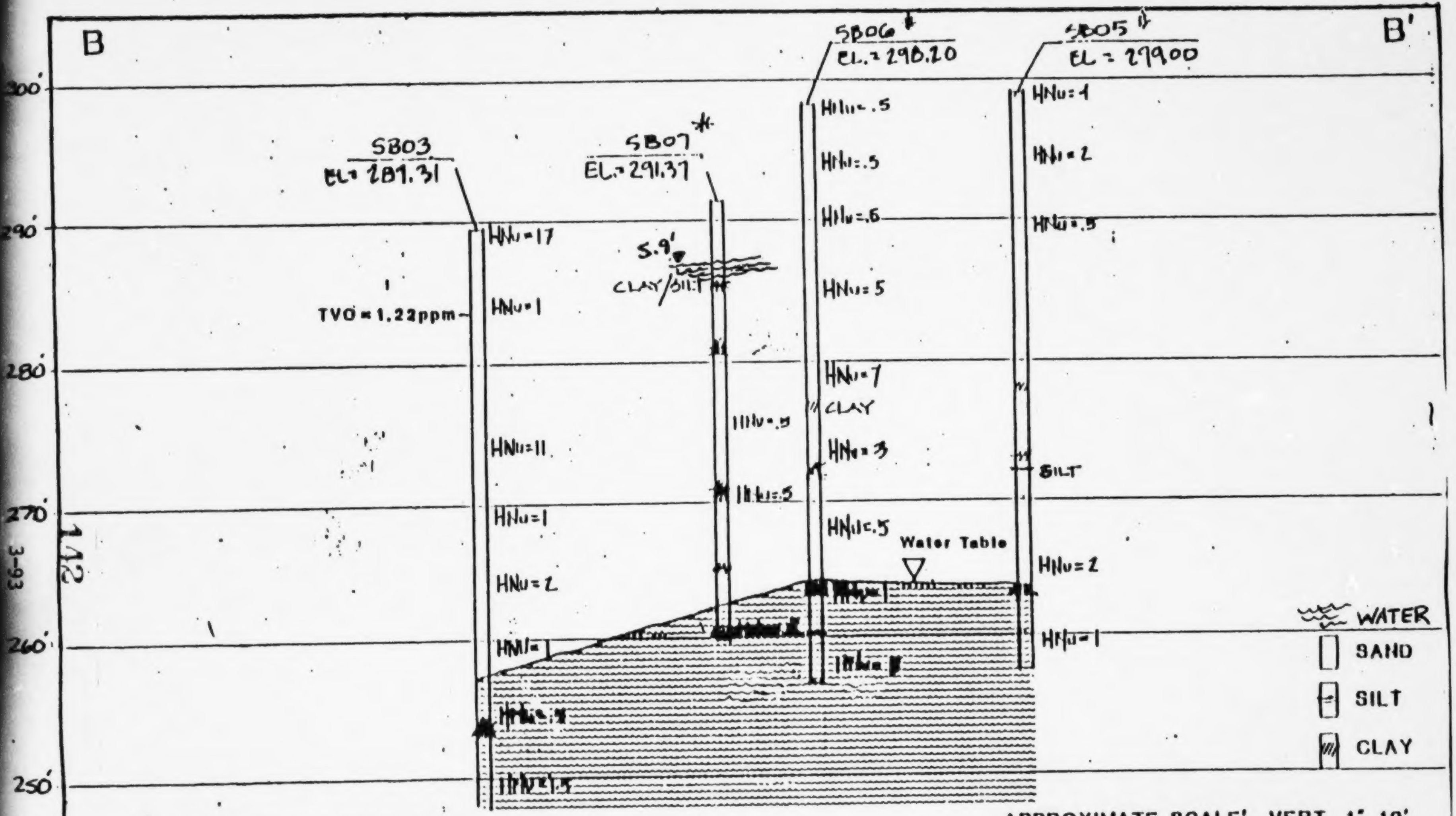
A
A'
SB01
EL=289.54
SB04*
EL=290.69
SB06*
EL=298.20
SB08*
EL=298.66
300'
290'
280'
270'
260'
250'
HNu=3
HNu=15
HNu=2
HNu=2
HNu=9
HNu=1
HNu=1
SILT/CLAY
HNu=3
HNu=1
HNu=1
HNu=1
SILT
HNu=3
HNu=1
HNu=.5
HNu=.5
HNu=.5
HNu=.5
HNu=7
CLAY
HNu=3
HNu=.5
[HNu=1
HNu=1]
HNu=4
HNu=.5
TVO=0.10ppm
Water Table
WATER
SAND
SILT
CLAY

APPROXIMATE SCALE: VERT. 1" 10'
HORIZ. 1" 100'

* NO DETECTABLE TOTAL VOLATILE ORGANICS (TVO) FOUND

SITE SECTION A-A'

FIGURE 3.3-21


B
B'
300'
290'
280'
270'
260'
250'
SB03
EL= 281.31
TVO = 1.22ppm
HNu=17
HNu=1
HNu=11
HNu=1
HNu=2
HNu=
SB07 *
EL.=291.37
5.9'
CLAY/SILT
HNu=.5
HNu=.5
SB06 *
EL.=298.20
HNu=.5
HNu=.5
HNu=.6
HNu=5
HNu=7
CLAY
HNu=3
HNu=.5
Water Table
SB05
EL = 299.00
HNu=1
HNu=2
HNu=.5
SILT
HNu=2
HNu=1
WATER
SAND
SILT
CLAY

* NO DETECTABLE TOTAL VOLATILE ORGANICS (TVO) FOUND

Note: SB07 Projected Approx. 90 feet North to Section Line

APPROXIMATE SCALE' VERT. 1" 10'
HORIZ. 1" 100'

SITE SECTION B-B'

FIGURE 3.3-22

TABLE 2.3-11

DATA FROM INSTALLATION OF MONITORING WELLS

Well	Elevation of Zone of Installation (ft MSL)	Permeability* (cm/sec)	Groundwater Elevation (ft MSL)	
			3/6/84	4/9/84
B-1 (soil)	209.0 - 224.8	1.7×10^{-4}	223.6	224.1
B-1 (rock)	188.6 - 204.9	4.5×10^{-6}	219.4	218.8
B-2A	131.5 - 148.5	8.3×10^{-6}	192.1	193.4
B-2B	153.9 - 160.8	$>> 10^{-2}$	200.9	203.0
B-2C	187.5 - 193.9	1.7×10^{-3}	frozen	203.1
B-3 (soil)	171.2 - 185.1	1.4×10^{-4}	176.8	176.5
B-3 (rock)	145.6 - 161.6	2.6×10^{-6}	170.3	168.9
B-4	28.6 - 65.1	9.3×10^{-5}	99.8	97.0
B-5 (soil)	150.5 - 158.4	2.8×10^{-5}	170.5	171.0
B-5 (rock)	132.6 - 147.6	1.2×10^{-5}	170.4	170.9

* Based on variable head permeability tests

Surficial Geology

The study area is located on a glacial outwash plain comprised of stratified sand, gravel, and boulders. Three major subsurface units are noted to be present near the site. These units consist of glaciomarine fine sands and gravels, reported overlying glaciofluvial (deltaic) stratified sands and gravels. Glacial till is noted to underlie the stratified sands.

Beneath the site the predominant soil type is a medium grained sand with lenses of silt and clay (see Figure 3.3-26 through 3.3-28). Approximately forty feet of these medium coarse grained sands beneath the site are unsaturated. An effective porosity of 0.2 (default value) was used for these sediments when saturated.

The glaciomarine fine sands, silts and clay silts reportedly overlie the sand and till along the steep slopes that lie adjacent to the river and its tributary brook. It was noted that the clayey glaciomarine deposits have apparently presented a barrier to ground water flow from the sand and gravel deposits (sand and till). Springs and seeps were noted to occur where this ground water flowing from the sand and gravel escapes to the surface through the clayey deposits.

Bedrock Geology

The topography of the bedrock surface generally slopes to the east, toward the river as shown in Figure 3.3-32. The bedrock surface forms a broad northeast-trending trough to the west of the site; the surface rises south of the site. This peculiar topography of the bedrock surface is a significant factor, which results in movement of groundwater toward the north away from the site.

The bedrock beneath the site is reportedly composed of granite, pegmatite or schistose migmatite, possibly transected locally by thin, tabular mafic dikes. Cores from the monitoring wells drilled in 1984 show moderately to heavily fractured rock with softening and iron staining due to weathering along the fractures. It was noted that ground water is transported through the bedrock apparently to the northwest in fractures, and to the north/northeast along the dikes. Calculated permeabilities from falling head permeability tests in the upper zone of the bedrock were reported to vary from 10^{-5} to 2.5×10^{-6} cm/sec.

Site and Near Site Hydrology

General information on the ground water hydrology of the surficial and bedrock aquifers in the vicinity of the site was noted to be given in a previous report, conducted in 1982. A study conducted in 1984 was designed to better define the ground water flow and to verify the inferences made relative to the hydrogeologic parameters of the area from the 1982 study. To this end, five monitoring wells were installed (B1-B5), in addition to the four previous monitoring wells installed in 1982 (B101-104). Figure 3.3-25 shows the location of the monitoring wells from both studies. Also note Table 3.3-16 on Well Data (1984).

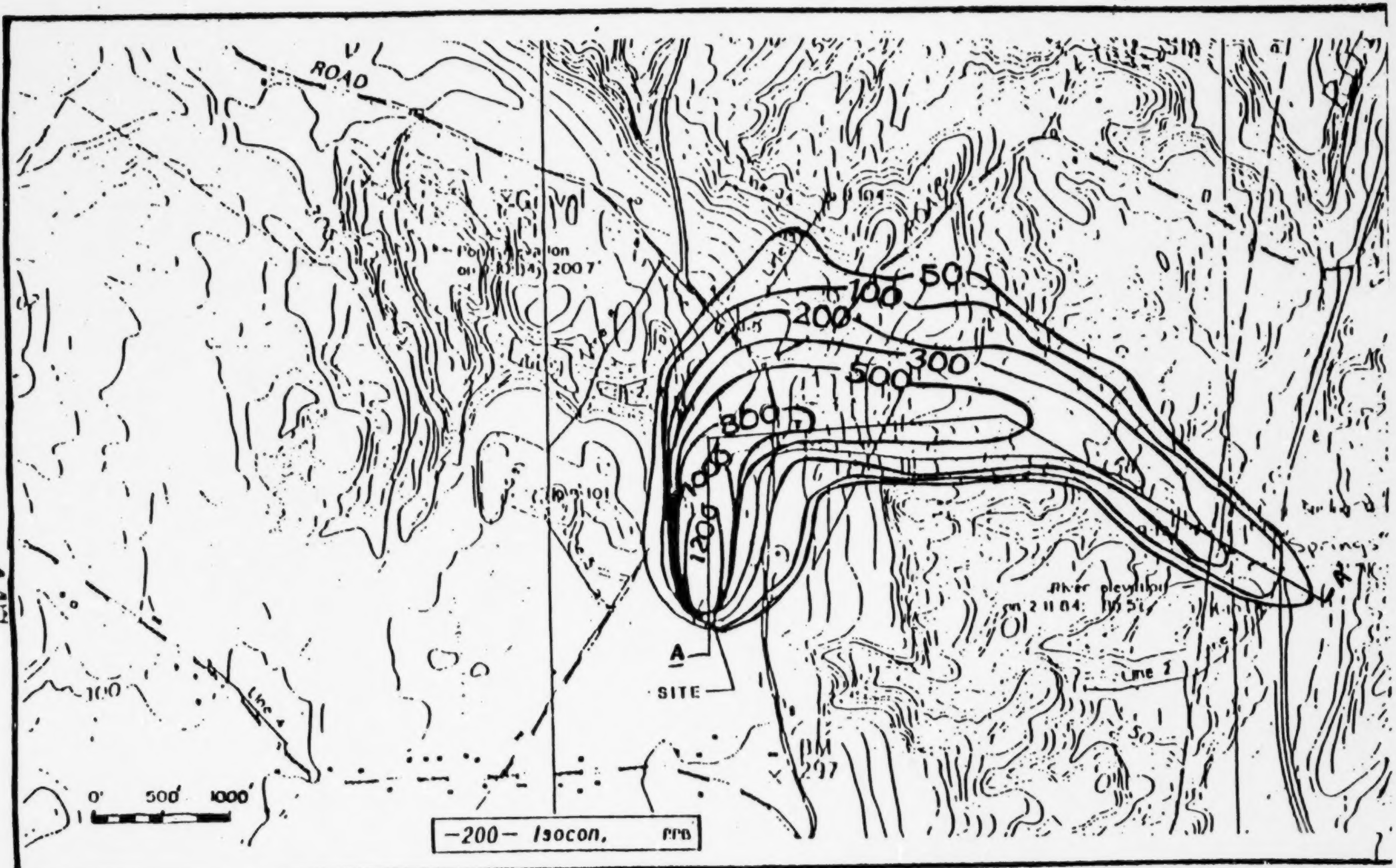
Wells B1 through B5 were installed in order to expand and address the need for further well data. This well information was intended to confirm the presence and migration of the contaminant plume, to delineate areas of high permeability, to assist in model calibration, and define areas of low permeablility thought to exist near the site.

The general path of ground water flow in the surficial aquifer was noted to be northwestward from the site, eventually turning eastward through an east-west trending coarse gravel deposit toward the "springs" (see Figures 3.3-29 and 3.3-30). Figure 3.3-31 gives the inferred bedrock potentiometric surface; flow direction was inferred to move to the northwest, as indicated by the arrows.

The aquifers are hydraulically connected as indicated by the presence of contaminants in the bedrock aquifer. Downward vertical gradients (i.e. a recharge zone) through the surficial aquifer were indicated by all the 1984 boring sites with multiple well installations.

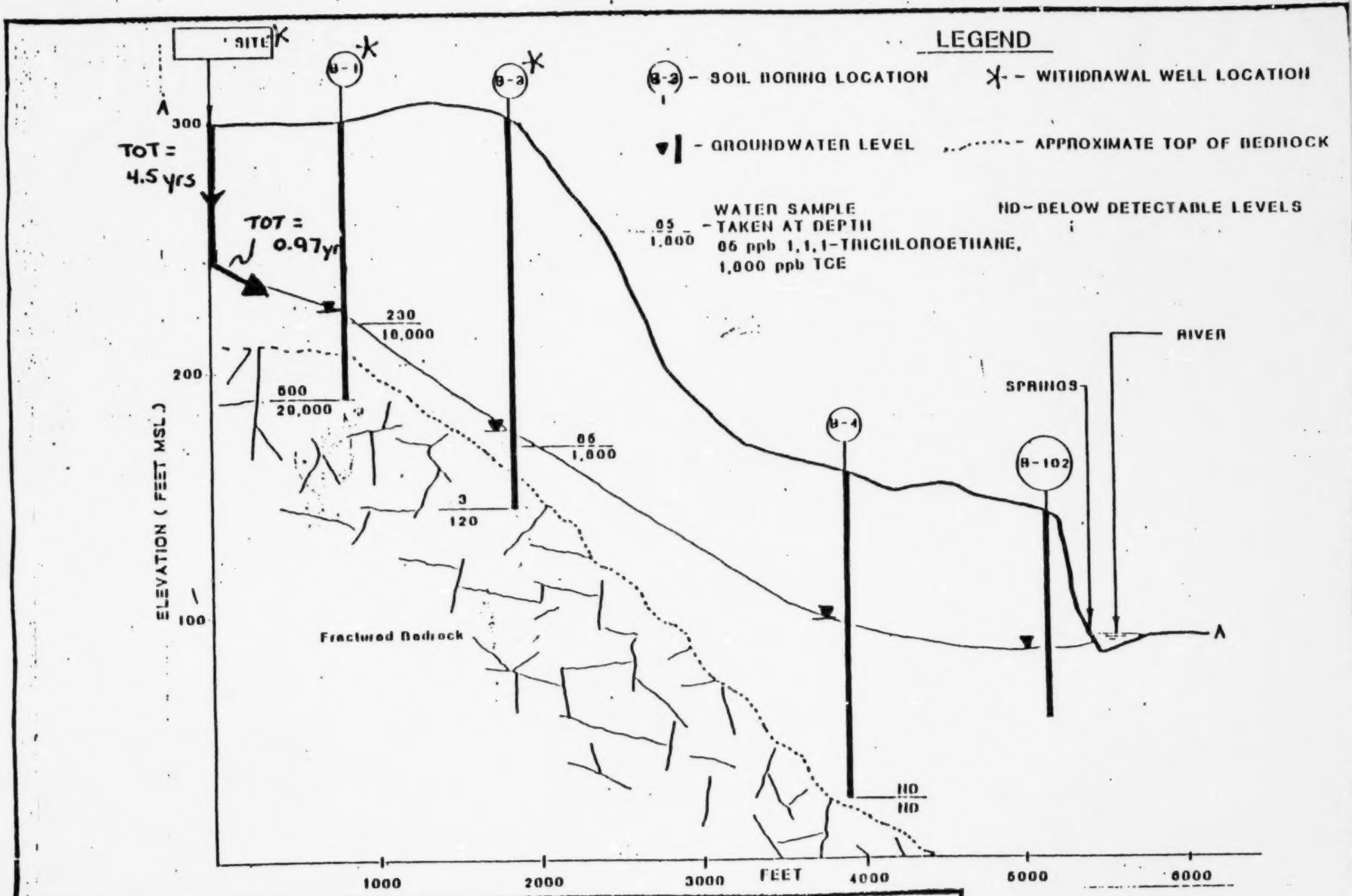
Plume Information

The path of contaminants leaving the site appears to be in a north-northwesterly direction; the contaminants then appear to take a larger radius turn (larger then that predicted by the 1982 study), before curving eastward and finally southeastward to intersect the river at the springs. Refer to the section on site and near site hydrology for well data used to confirm the contaminant plumes path. Also see Figures 3.3-29 through 3.3-32. The report also noted that most of the bedrock ground water that originates at the site is discharged to the overlying gravel deposits in the vicinity of the springs.


ROAD
50
100
200
300
500
800
1000
1200
A
SITE
A'
Springs
Line 1
Line 4
100
50
0'
500'
1000'
-200- Isocon. ppb
N

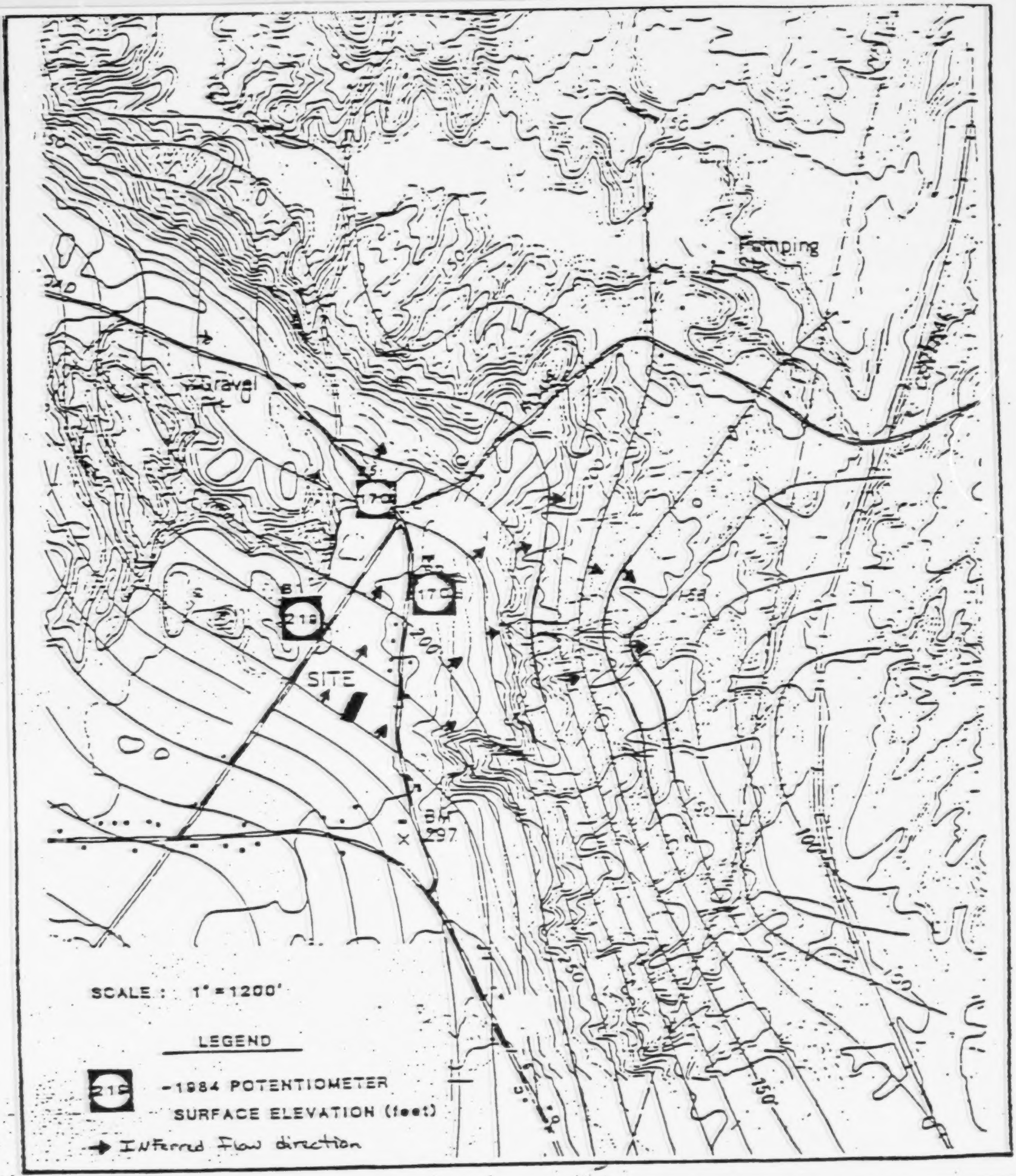
INFERRED SURFICIAL AQUIFER PLUME FROM
Section A-A'

FIGURE 3.3-23


LEGEND
B-3 - SOIL BORING LOCATION
- WITHDRAWAL WELL LOCATION
- GROUNDWATER LEVEL
- APPROXIMATE TOP OF BEDROCK
05/1,000 - WATER SAMPLE TAKEN AT DEPTH 06 ppb 1,1,1-TRICHLOROETHANE, 1,000 ppb TCE
ND - BELOW DETECTABLE LEVELS
SITE
A
TOT = 4.5 yrs
TOT = 0.97 yr
B-1
B-3
B-4
B-102
230/10,000
600/20,000
06/1,000
3/120
ND/ND
SPRINGS
RIVER
A
Fractured Bedrock
ELEVATION (FEET MSL)
300
200
100
1000
2000
3000
FEET
4000
5000
6000

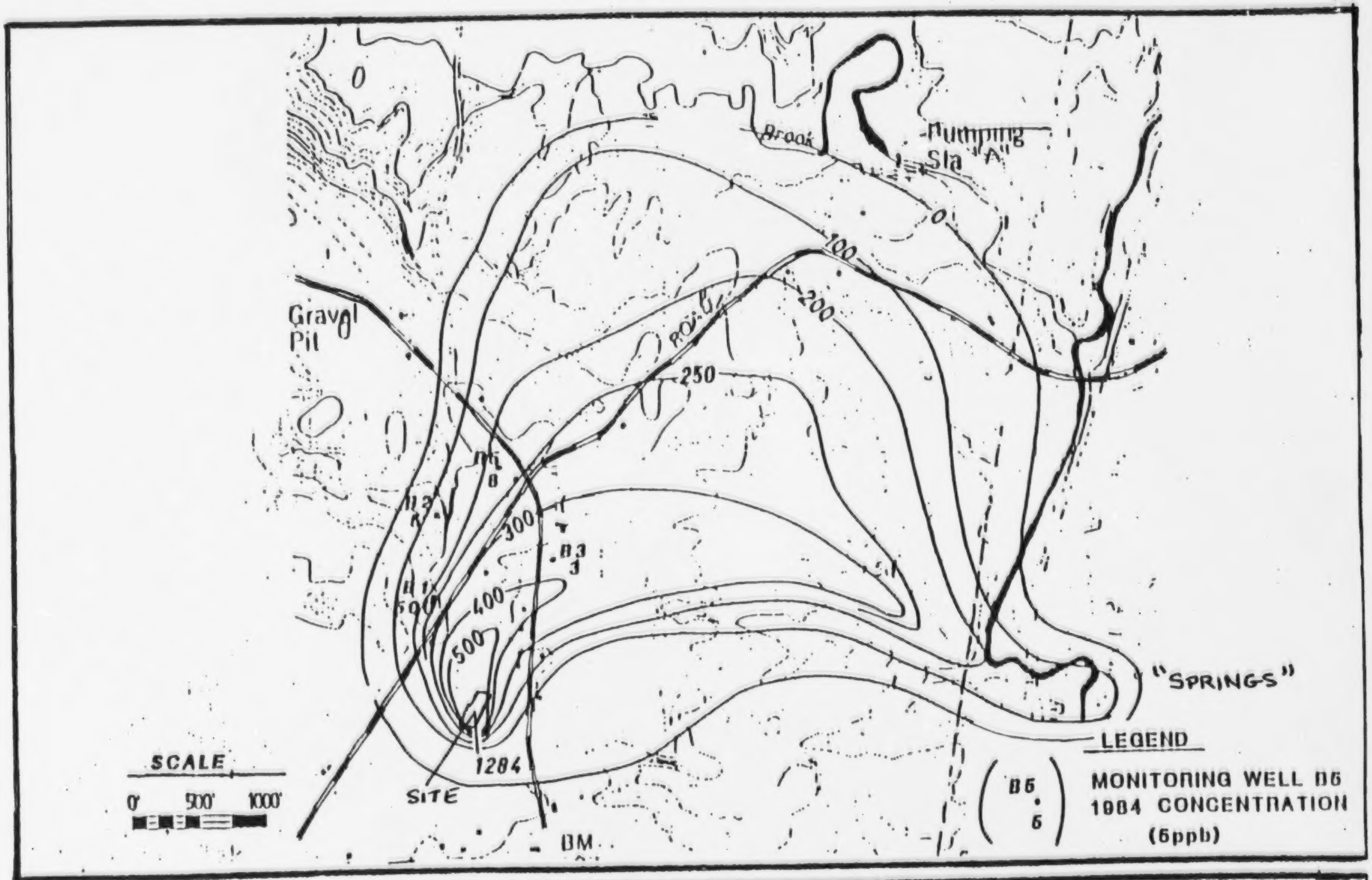
SUBSURFACE CROSS-SECTION A-A FROM SITE TO RIVER
(see Figure 2.3-23 for Cross-Section Location)

FIGURE 3.3-24


50
50
50
240
Gravel
Pumping
175
170
B1
218
170
200
SITE
BH
297
50
100
250
150
150
SCALE : 1" = 1200'
LEGEND
218 -1984 POTENTIOMETER SURFACE ELEVATION (feet)
→ INferred Flow direction

INFERRED BEDROCK POTENTIOMETRIC SURFACE FROM (1982) WITH 1984 DATA SUPERIMPOSED

FIGURE 3.3-25


0
Brook
Pumping Sta "A"
0
100
200
Gravel Pit
Road
250
B1
0
B2
300
B3
3
B1
500
400
500
1284
SITE
BM
"SPRINGS"
SCALE
0' 500' 1000'
LEGEND
B6 • 6
MONITORING WELL B6
1984 CONCENTRATION
(6ppb)
N

INFERRED BEDROCK AQUIFER PLUME FROM 1982 STUDY
WITH THE 1984 1,1,1-TRICHLOROETHANE OBSERVED DATA SUPERIMPOSED

FIGURE 3.3-26

Time of Travel-TOT_{100}

Approximately 40 feet of unsaturated medium-textured sands are encountered cirectly beneath the site. The analytical approach to solving for TOT within the unsaturated zone was based on a single-layered system of a single material type. This solution assumes that the hydraulic gradient is equal to 1.[1] A steady state flow of moisture through the unsaturated zone is also assumed. Steady state flux (q) is assumed to be equal to net precipitation where evapotranspiration and run-off are assumed nonexistent. This provides the maximum flux for the site.

- Unsaturated Zone

$$\mathrm{TOT}_{unsat.} = \frac{LO}{q}$$

L = Length of unsaturated column
O = Volumetric water content approximately equal to porosity
q = Flux

$$\mathrm{TOT}_{unsat.} = \frac{(1.22 \times 10^{3}\ \mathrm{cm})(0.395\ \mathrm{cm}^{3}/\mathrm{cm}^{3})}{107\ \mathrm{cm/year}}$$

$$\mathrm{TOT}_{unsat.} = 4.5\ \text{years}$$

- Saturated Zone

$$V = \frac{Ki}{ne}$$

K = 3.28×10^{-4} ft/sec (default value)[2]
i = 0.02 average from field data
ne = 0.2 (default value)

$$V = 3.28 \times 10^{-5}\ \mathrm{ft/sec}$$

$$\mathrm{TOT}_{100} = \frac{100\ \mathrm{ft}}{3.28 \times 10^{-5}\ \mathrm{ft/sec}} = 3.05 \times 10^{6}\ \mathrm{sec} = 9.67 \times 10^{-2}\ \mathrm{yrs}$$

$$\mathrm{TOT}_{100} = \mathrm{TOT}_{unsat.} + \mathrm{TOT}_{sat.}$$
$$\mathrm{TOT}_{100} = 4.6\ \text{years}$$

---

1 - Derived from Technical Support for Developing Guidance for Calculating Time of Travel (TOT) in the Unsaturated Zone; December, 1984, Section 3.

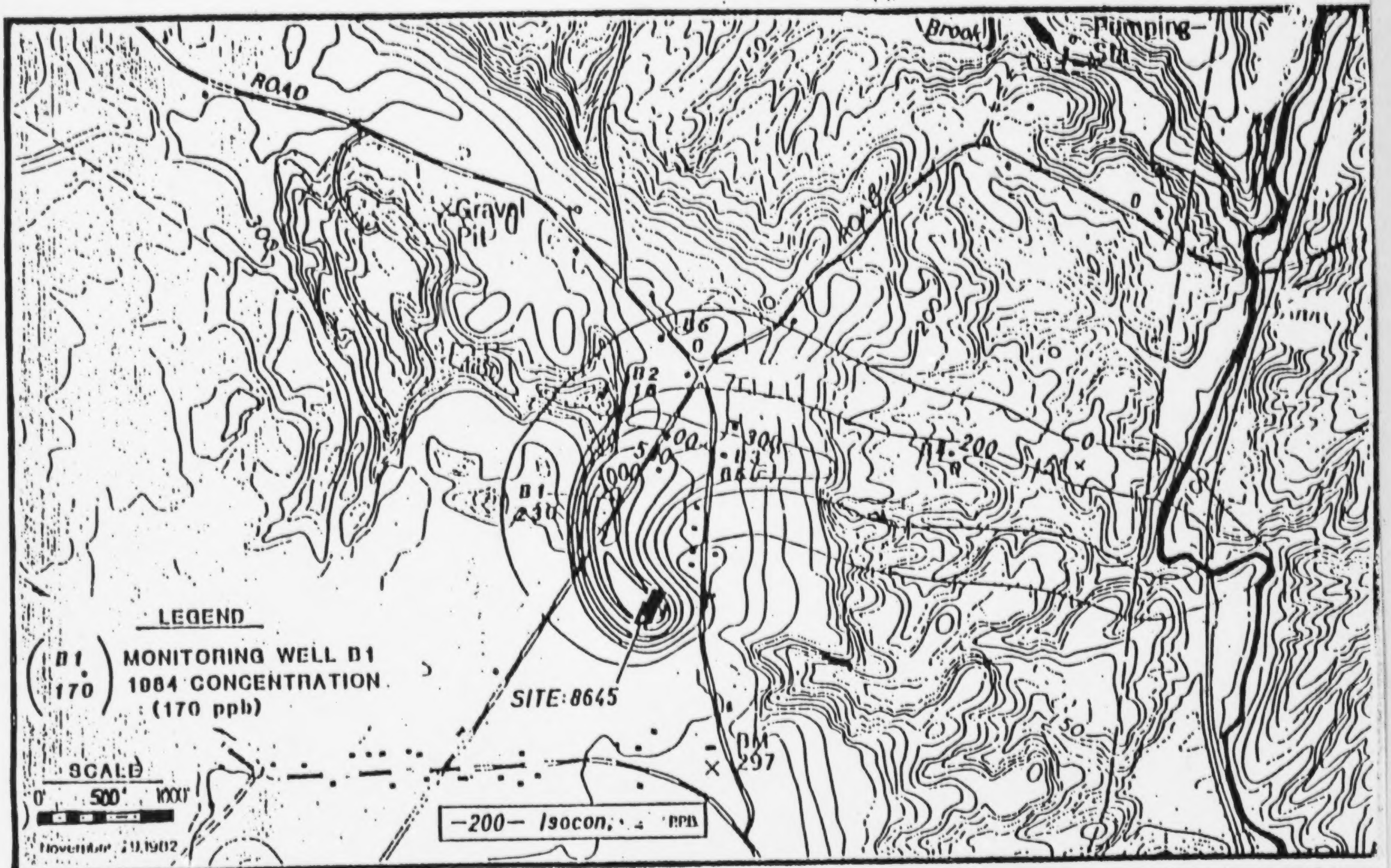
2 - Default value for hydraulic conductivty taken from Freeze & Cherry, 1979. K selected for clean sand is 1×10^{-2} cm/sec. Conversion factor for ft/sec = 3.28×10^{-2}.

Health Risk Assessment

This health risk assessment characterized hypothetical risks associated with the lifetime consumption of ground water contaminated with trichloroethylene (TCE) and 1,1,1-trichloroethane, the major contaminants for this site. While actual contamination of private well water supplies near the site has occurred, these data were not available for use in this case study and therefore the potential risks to residents who were exposed to contaminated drinking water will not be evaluated here.

Hypothetical risks associated with the lifetime consumption of ground water containing TCE and 1,1,1-trichloroethane (two potential human carcinogens) will be based on the maximum contaminant concentrations identified in 1984 in a bedrock monitoring well (B-1) located in the centerline of the plume. Figure 3.3-33 shows the location of B-1 and Table 3.3-17 contains the sampling results. Contaminant concentrations are generally higher in the bedrock aquifer than in the surficial aquifer. Well B-1 is located off-site at roughly 1000 feet northeast of the site; it corresponds to a well location between points A and D on Figure 3.2-1. Well B-1 data were collected in 1984. Drinking water has been obtained from both the bedrock and surficial aquifers. Thus, using the data available in the RI for this site, worst-case risk estimates will be produced.

For 1,1,1-trichloroethane, and additional risk esimate was made based on the maximum isoconcentration line shown in Figure 3.3-33; the concentration gradients shown in Figure 3.3-33 apply to the surficial aquifer and are based on historical and


ROAD
Brook
Pumping Sta
Gravel Pit
ROAD
300
200
50
B6
0
B2
18
B1
230
1000
500
300
200
DM
297
SITE: 8645
LEGEND
B1
170
MONITORING WELL B1
1984 CONCENTRATION
(170 ppb)
SCALE
0' 500' 1000'
November 29,1982
-200- Isocon. ppb
N

INFERRED SURFICIAL AQUIFER PLUME FROM 1982 DATA WITH THE 1984 1,1,1-TRICHLOROETHANE OBSERVED DATA SUPERIMPOSED

FIGURE 3.3-27

TABLE 3.3-12

LABORATORY ANALYTICAL RESULTS OF GROUNDWATER QUALITY MONITORING

Location	Date (1984)	1,1,1 Trichloroethane (ppb)	Trichloroethylene (TCE) (ppb)
B-1 (shallow soil)	3/21	170** (230)	16,000
B-1 (bedrock)	3/21	470** (500)	29,000
B-2 (shallow soil)	3/22	9	91
B-2 (deep soil)	3/22	16	160
B-2 (bedrock)	3/22	5	56
B-3 (shallow soil)	3/20	65	1,800
B-3 (bedrock)	3/20	3	120
B-4 (deep soil)	3/21	ND	ND
B-5 (deep soil)	3/20	ND (ND)*	ND (ND)*
B-5 (bedrock)	3/16	7 (8)*	190 (177)*

---

* duplicate
ND = not detected

** These samples were diluted for the analysis of trichloroethylene. The companion results in parentheses for 1,1,1-trichloroethane are for the undiluted sample.

TABLE 3.3-13. INCREMENTAL CARCINOGENIC RISK ASSOCIATED WITH LIFETIME CONSUMPTION OF TCE AND 1,1,1-TRICHLOROETHANE CONTAMINATED GROUND WATER

Contaminant	Concentration (ppb)	Average Daily Lifetime Dose* (mg/kg/day)	CAG Potency Estimate $(mg/kg/day)^{-1}$	Incremental Carcinogenic Risk
Trichloroethylene	29,000	0.83	1.9×10^{-2}	1.6×10^{-2}
1,1,1-Trichloroethane	500	0.014	1.6×10^{-3}	2.2×10^{-5}
	1,000	0.028	1.6×10^{-3}	4.4×10^{-5}

* Assumes lifetime ingestion of 2 liters/day of drinking water by a 70 kg. adult

current (1984) data.

The carcinogenic risks associated with the lifetime consumption of TCE and 1,1,1-trichloroethane are given in Table 3.3-18. The risk from TCE ingestion over a lifetime is estimated at 1.6×10^{-2}, which is extrememly high. For 1,1,1-trichloroethane, the estimated risk is 2.2 and 4.4×10^{-5}.

While the concentrations of contaminants found in the sixteen private wells that were closed in 1977 are not reported in the RI, it can be assumed that by virtue of the wells being capped, the risks were considered to be unacceptable.

Exposure Assessment

Exposure to ground water contaminants from this site has occurred. As previously stated, 16 private wells in the path of the plume were closed in 1977. In 1978 a public water supply was provided as replacement for these wells. Future exposure via ground water ingestion is unlikely because of the provision of this new water supply. However, unless land use controls are instituted to prevent utilization of the contaminated aquifer, exposure could occur in the future from well water installation.

The plume is migrating to the north and northwest and eastward to a river and brook. Based on data in the site RI report, no contamination has been found in these downgradient surface waters. Potential future risks associated with the river and brook would depend on the remedial actions taken on the site, where significant soil contamination exists that could contribute to overland flow and infiltration to ground water. The brook (as Class B-2 water) could theoretically, under state regulations, be used for drinking water if treated. Relatively low-level contamination of a spring adjacent to the river has occurred, the spring being a discharge point for the contaminated ground water. The potential for exposure to contaminants in the spring is not known from information provided in the RI.

4.0 ESTIMATING THE NUMBER OF FACILITIES LOCATED IN VULNERABLE GROUND-WATER SETTINGS

The analytical approach and methodology followed to estimate the number of hazardous waste land treatment, storage, and disposal (TSD) facilities located in vulnerable ground-water settings, and the results obtained, are discussed in this Section.

The optimal approach to determine the number of hazardous waste TSD facilities in vulnerable settings would be to evaluate the ground-water vulnerability of each facility in the U.S. on a facility-specific basis. However, an evaluation of all facilities was not possible due both to the lack of available hydrogeologic data on TSD facilities and to the time constraint placed on the completion of the analysis. As a result, a pragmatic approach was developed necessarily that uses only currently available data.

4.1 METHODOLOGY

Ground-water vulnerability is evaluated in terms of TOT_{100}, the time of travel of ground water along a 100-foot flow line originating at the water table at the base of the hazardous waste unit. In the absence of facility-specific information for all facilities in the U.S., other readily available databases containing information useful for the analysis were identified. Several databases were reviewed for hydrogeologic information that could be used to calculate TOT_{100} and evaluate ground-water vulnerability.

As described in detail in the guidance criteria, the calculation of TOT_{100} requires data on hydraulic conductivity, hydraulic gradient, and the effective porosity of the geologic media underlying the facility. These data are explicitly required in a Part B application, and are used to calculate the average linear velocity (V) of ground-water flow. Based upon the criteria outlined in the guidance, travel distance is set at 100 feet; therefore, ground-water velocity essentially dictates whether a facility pases the TOT_{100} criteria.

Additional data requirements for the analysis were EPA facility ID number, address, and latitude and longitude. These data are necessary to identify facility location and ascertain overlap between the various databases. The following databases were identified as being potentially useful for characterizing ground-water vulnerability:

- HWDMS database - the hazardous waste data management system database includes information on process codes based on Part A permit application data, and regional updates. This database provides the best representation of the "universe" of RCRA hazardous waste TSD facilities, including landfills, surface impoundments, and waste piles.
- 1982 GCA Study - GCA Corporation prepared a comprehensive database of geographical, geological, and hydrological variables to characterize the hydrogeology of 346 sites.

- 1983 G&M Study - Geraghty & Miller designed 18 flow field scenarios to correspond to the 18 generic hydrogeologic settings developed by GCA Corporation (1982) based on data for 346 existing sites. G&M established a rational basis for simulating flow rates and patterns by applying flow system theory, professional experience, and literature reviews. Selected pairs of flow fields having similar hydrogeologic characteristics were clustered into flow systems, reducing the total number of flow systems from 18 to 14.
- WA23 Database - EPA's Office of Solid Waste (OSW) and Pope-Reid Associates collected data from Part B applications to develop a worst-case hydrogeologic scenario. Sufficient data were collected from 163 hazardous waste disposal facilities nationwide to create a computer database. The database contains two files; a ground-water characteristics file and a stratigraphic (soil) conditions file.
- 1985 GCA Study - GCA is currently conducting a study for OSW. They have collected data on approximately 225 sites (RCRA, CERCLA, USGS, municipal) and are analyzing the data for quantitative information that can be used in calculating TOT, and risk or environmental performance criteria. Approximately 60 of the sites have been analyzed, of which 37 are RCRA facilities.

- EPA Case Studies - case studies for 10 RCRA-permitted hazardous waste land TSD facilities and one Superfund remedial action site were developed and included as Technical Methods for Evaluating Facility Locations: Technical Resource Document.

The databases were evaluated in terms of the information that they could provide on hydrogeology on the sites, aquifer type, ground-water quality, location, and facility type. Facility types analyzed are limited to landfills, surface impoundments (treatment, storage, and disposal), and waste piles. Other facility types such as deep well injection, are not considered.

A review of available information and relevant databases revealed three potential approaches for determining TOT_{100}. The first approach, to review all available RCRA hazardous waste land TSD facility Part B permit applications and calculate TOT_{100} for each facility, would have yielded the most accurate results because it employed detailed facility-specific data. However, it was rejected for two reasons: (1) the relatively small number of Part B applications available (roughly 150); and (2) the time necessary to carry out the approach. Gathering the needed data from EPA Regional Offices would have required more time than was available for this analysis.

The second approach was to use the 1982 GCA and 1983 G&M studies to calculate TOT_{100} for 14 aquifer flow regimes, based on data from the 346 land TSD facilities, and project the findings for these facilities to the HWDMS universe by statistical methods. This approach was also rejected because it was based entirely on the generic flow regimes for the determination of TOT_{100}, and failed to employ any facility-specific data.

The third approach, which was selected, was to augment the second approach by combining 173 generic TOT_{100} calculations with as many (55) facility-specific determinations as could be made from available data, short of analyzing Part B applications. This approach balances the desire to maximize the number of facilities measured with the need to rely as heavily as possible on facility-specific data.

All three approaches are less than ideal in that they require the extrapolation of results from a facility sample to estimate the number of facilities that are in vulnerable settings. The statistical validity of any such extrapolation is unclear since insufficient information exists to determine what would be a hydrogeologically representative sample of facilities. However, the third approach has the advantage of employing both facility-specific and flow regime classification data. This approach allowed evaluation of the more generic flow regime approach by comparing the results of the flow regime analysis to the results of the facility-specific analysis, while making the best use of the available data. Therefore, the third approach was judged to be the best available procedure for estimating the total number of facilities potentially subject to the ground-water vulnerability criterion.

The vulnerability designation was determined by comparing EPA vulnerability guidelines to the TOT_{100} of the facility. A designation of vulnerable, non-vulnerable, or non-vulnerable (storage) was assigned to each facility.

"Vulnerable" facilities are those for which TOT_{100} is less than on the order of 100 years for disposal facilities or, for treatment facilities, for which TOT_{100} is too short to implement a Corrective Action Plan. "Non-vulnerable" facilities were divided into two categories. "Non-vulnerable (storage)" represents those treatment or storage facilities located over ground water in settings where TOT_{100} exceeds the time in which a Corrective Action Plan can be implemented. "Non-vulnerable" represents the remainder of non-vulnerable facilities, i.e., those in settings where TOT_{100} exceeds on the order of 100 years.

4.2 RESULTS

TOT_{100} was determined for 228 facilities including 55 facilities for which facility-specific data were used and 173 for which the G&M flow regimes served as the basis for generic TOT_{100} calculations. However, some of these facilities have lost interim status (LOIS) as a result of failure to certify compliance with certain ground-water monitoring requirements of the Hazardous and Solid Waste Amendments of 1984. The HWDMS database provides information on facilities that have survived LOIS. A July 21, 1986 HWDMS printout indicated that 171 of the 228 facilites for which TOT_{100} was determined were still accepting wastes. Table 4-2-1 presents by EPA Regions the vulnerability status of these 171 facilities.

TABLE 4.2-1 DISTRIBUTION OF FACILITIES BY REGION (VULNERABLE, NON-VULNERABLE, NON-VULNERABLE (STORAGE))

Region	#Vulnerable	#Non-vulnerable	#Non-vulnerable (storage)
1	11	-	-
2	7	1	-
3	10	2	-
4	18	1	1
5	17	8	10
6	26	19	4
7	5	1	-
8	8	-	-
9	14	2	1
10	4	1	-
Totals	120	35	16

The results indicate that the majority (120, or 70%) of the 171 facilities are located in vulnerable ground-water settings. The vulnerability status may be affected by errors in the TOT_{100} calculations and errors that may be caused by variations in the quality of hydrogeologic data in the databases. Some errors in classification have already been identified and are being corrected. TOT_{100} values for the sites included in the analysis vary from much less than one year to more than 1000 years, but insufficient information is available to warrant the rigorous construction of a distribution of TOT_{100} values, which would perhaps allow the effect of TOT_{100} on vulnerability to be evaluated stochastically.

4.3 CONTINUING EFFORTS

The EPA will continue to examine specific hazardous waste land TSD facilities in various hydrogeologic settings to further the facility location standards development program. Currently, a preliminary classification scheme has been designed for the purpose of selecting the possible settings that may adequately correspond to a wide range of TOT_{100}s. Therefore, rather than covering all hydrologic/physiographic/hydrogeologic provinces, the scheme covers all the physical settings that govern TOT_{100} from the surface to the uppermost aquifers or close receptors.

The classification scheme considers two basic systems: an unconsolidated overburden (Regolith) and an underlying bedrock system. As applied to the TOT_{100} concept, each system is classified according to its ability to allow water to flow through it.

TABLE 4.3-1 GEOLOGIC SETTINGS

Regolith Systems	Bedrock System
1. Thin or absent	a) Aquifer b) Aquitard
2. Alluvium/Aeolian	a) Aquifer b) Aquitard
3. Alluvium/Aeolian with confining layer	a) Aquifer b) Aquitard
4. Clay	a) Aquifer b) Aquitard
5. Clay over unconsolidated aquifer	a) Aquifer b) Aquitard
6. Unsaturated sand	a) Aquifer b) Aquitard
7. Permeable Glacial	a) Aquifer b) Aquitard
8. Impermeable Glacial	a) Aquifer b) Aquitard

TABLE 4.3-2

Regolith Systems
(Unconsolidated soils sediment cover overlying bedrock)

1. Thin or absent: Is not a factor in water infiltration

2. Alluvium/Aeolian: Unconsolidated material overlying bedrock. Capable of allowing water to infiltrate and be stored or move. Deltaic, fluvial, coastal, aeolian sands, gravel, loam, non-glacial in origin. May contain silt/ clay lenses, overbank deposits. Can be the uppermost aquifer, and also reach great thicknesses.

3. Alluvium/Aeolian with confining layer: Similar to (2) above, but with a confining layer (unconsolidated) between it and bedrock, such that it will restrict flow to bedrock locally.

4. Clay: Any considerable thickness of clay size material overlying bedrock. Can be saprolite, lake deposits, peat, etc. It impedes infiltration to bedrock.

5. Clay over unconsolidated aquifer: Similar to (4) above. The implication is that it is not a recharge area for the underlying aquifer.

6. Unsaturated sand: Similar in texture to (2) above, but lack of recharge makes it unsaturated.

7. Permeable glacial: Glacier related sediments with varying degree of permeability. Includes outwash, eskers, stratified drift, sandy/bouldery till, glaciofluvial, glaciomarine, brittle glacial till, etc.

8. Impermeable glacial: "Tight" glacial deposits such as clayey till, lacustrine deposits, etc.

TABLE 4.3-3 BEDROCK SYSTEMS

A. Bedrock Aquifers

   1. Includes sedimentary and crystalline rocks that exhibit secondary porosity due to:

      - Faults
      - Fractures, joints, and cleating (coal)
      - Foliation and schistocity
      - Karst (limestone, dolomite, gypsum)
      - Weathered horizons (& unconformities)
      - Narrow intrusion (dikes)

   2. Poorly cemented and bedded sandstone and carbonate rocks

   3. Thin bedded sequences of sedimentary rocks

   4. Basalt flows

B. Bedrock Aquitards

   1. Well cemented, unaltered elastic and chemical sediment

   2. Unaltered crystalline rock

Table 4.3-1 shows the eight different classes in the Regolith system and the two classes of bedrock that can be applied to each overburden class. Table 4.3-2 presents the conceptual definition of each Regolith class, and Table 4.3-3 presents the conceptual definition of each Bedrock Class.

These preliminary combinations cover a wide range of TOT_{100}s. Since the classification scheme is not based on geographical location, a site can be further described as belonging in a specific location, such as the "glaciated Appalachian Region." One may find a second case study that fits the same TOT_{100} classification, but is located in the "glaciated Central Region." In such a case, there will be no need to include both sites as case studies since that specific TOT100 setting is represented by either one.

The intent of this continuing effort is to determine whether case study or modeled characterizations exist for each of the major geologic categories. If characterizations are lacking, they will be formulated and refined during the location standards development process.

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ATTACHMENT 1

APPLICATION OF LINER LOCATION MODEL TO THE ANALYSIS OF TIME-OF-TRAVEL CRITERIA FOR SITING OF NEW LAND DISPOSAL FACILITIES

Prepared by Geraghty & Miller, Inc.

Geraghty & Miller, Inc.

APPLICATION OF LINER-LOCATION MODEL TO THE ANALYSIS OF TIME-OF-TRAVEL CRITERIA FOR SITING OF NEW LAND DISPOSAL FACILITIES

DRAFT FINAL REPORT

Prepared For:

U.S. ENVIRONMENTAL PROTECTION AGENCY
LAND DISPOSAL BRANCH
OFFICE OF SOLID WASTE
Washington, D.C. 20460

EPA CONTRACT 68-01-6871
WORK ASSIGMENT NO. 34

By:
GERAGHTY & MILLER, INC.
ANNAPOLIS, MARYLAND 21401

January 1985

PREFACE

This report was prepared by Geraghty & Miller, Inc. (G&M) in fulfillment of Work Assignment 34 under the U.S. Environmental Protection Agency (EPA) Contract 68-01-6871. It will be incorporated by GCA Corporation into a larger report that will deal with the technical issue of selecting criteria that control the siting of new hazardous waste land disposal facilities. The work is being performed for the Office of Solid Waste (OSW) which has the objective of establishing a scientific basis for a working definition of the term "vulnerable ground water". The present working definition is based on a time-of-travel (TOT) to a standard distance measured along a ground-water flow line. Ground water under landfills and disposal surface impoundments is considered non-vulnerable if the TOT is equal to or greater than 100 years. Ground water under storage impoundments and waste piles is considered non-vulnerable if the travel time is equal to or greater than 10 years.

Both hypothetical studies and real site case studies are being developed in order to examine the health risks of exposure to various chemicals and a range of hydrogeologic settings that would bracket the above TOT criteria. G&M and ICF, Inc., are performing model studies with the liner-location model, while Geotrans is performing site-specific model studies to assist GCA in their analyses.

The EPA technical project monitor for this study was Mr. Seong Hwang of the Land Disposal Branch (LDB) under the direction of Mr. Arthur Day. The Project Manager and Quality Assurance Officer for G&M were Don A. Lundy and Jeffrey P. Sgambat, respectively. Other members of the G&M team included Messers. Glenn Duffield and Robert Wright. G&M also acknowledges significant input from the Project Manager at GCA Corporation, Mr. Alfred Leonard and at ICF, Mr. Baxter Jones.

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SUMMARY

Geraghty & Miller, Inc., (G&M) worked with ICF, Inc., and GCA Corporation to adapt and apply an existing set of computer models developed for the 1984 liner-location project of the Economics Analysis Branch of OSW for the assessment of health risks associated with a range of time-of-travel (TOT) conditions on hypothetical sites.

G&M developed six generic vertically-oriented ground-water flow fields and a standardized contaminant source term for simulation of contaminant mass transport to a downgradient monitor well. A range of ground-water velocities was selected to represent a range of TOTs to a well, i.e., for travel along a 100-ft ground-water flow line that originates at the center of the source and terminates at a monitor well.

The source term is conceptualized as a line source with dimensions of 1-foot wide and 32.8 ft (10 m) long. This source has mass loading characteristics of either a generic landfill or a storage surface impoundment. The source life and strength for the landfill source is estimated assuming an original mass in storage of 6 kg/ft^2, a leaching rate determined by an assigned contaminant concentration in the concentration in the leachate and a facility leakage rate controlled by ground-water velocities in the underlying flow field. The source life for the surface impoundment source is arbitrarily set to 30 years; source strength is controlled by an assigned contaminant concentration and a leachate release rate dictated by the flow field.

To simulate these conditions, G&M used the Random-Walk particle tracking code of Prickett, et al. (1981). A standard mass input of one kilogram over a one-year time step produces a standard breakthrough curve of concentration vs. time at the well for each flow field. Contaminants are assumed to have one of two mobilities based on earlier work in the liner-location project. Each mobility class represents three specific contaminants selected by GCA for risk analyses:

Mobility Class 1 (Rd = 1.3)	Mobility Class 2 (Rd = 32)
Acrylonitrile	Benzene
Phenol	Xylene
Chromium VI	Nickel

With input from G&M, ICF adjusted the standard breakthrough curves to account for the following:

- Concentration in the leachate (either equal to saturation or 1/10 saturation concentration)
- Leachate release rate (controlled by the underlying flow field)
- Dispersion in the third dimension (at a right angle to the vertical plane of the flow field)

Attenuation and time delays caused by transport through the unsaturated zone and biodegradation in the saturated zone are ignored in the analysis. With a modified liner-location model code, ICF simulated contaminant concentrations and individual health risks at the end of the following time periods: 50, 100, 200, 500, and 1000 years, and at steady state, for the landfill and surface impoundment sources with the above two source concentration assumptions.

G&M studied the relationship of peak concentrations to ground-water velocities and TOT under both equal and flow field-controlled mass input conditions. Equal mass inputs could be controlled by either the facility design/failure mode or an underlying unsaturated zone. Unequal flow field controlled inputs would be the expected result of a low-permeability and/or low-flux environment.

For all hydrogeologic settings considered, except those involving diffusion-controlled transport with large (two-orders-of-magnitude) contrasts between multilayer velocities, peak concentrations produced by equal mass releases at the source are inversely related to velocity and positively related to TOT. Where mass releases are controlled by the flow field, concentrations are positively related to velocity and inversely related to TOT for all settings, including diffusion-controlled transport with high velocity contrasts.

The apparent reversal of relationships between concentration and velocity/TOT points up the importance of the source term in the model. It also raises an issue concerning to what degree low-velocity flow fields will actually limit mass loadings from facilities located in these settings. G&M believes that in most cases mass loading rates are controlled by the underlying flow field.

From this modeling study, it is clear that the lowest concentrations are associated with settings that involve very low velocity surficial layers (with diffusion-controlled transport) overlying an aquifer that would otherwise have received higher inputs of contaminants and would not have met current TOT criteria.

INTRODUCTION

This report will document the application of a Random-Walk mass transport model for estimating concentrations of contaminants at hypothetical wells downgradient of a leaking generic landfill or storage surface impoundment. The model application is an extension of an earlier modeling study by G&M which constituted part of Phase I of the liner-location project for the Economic Analysis Branch (EAB) (Geraghty & Miller, Inc., 1984). The current study for Land Disposal Branch (LDB) draws heavily from the previous study which is now documented in a draft final report entitled "Liner-Location Risk Analysis Model". Several significant changes were required in applying the model to the current study, as documented below.

Model scenarios developed in the liner-location project were based in part on a national survey of water-supply aquifer characteristics. Ground-water velocities assigned to model flow fields in that project ranged from about 1.6 to 33,000 ft/yr (0.5 to 10,000 m/yr). For that reason, they essentially represented 100-ft time-of-travel (TOT) scenarios that would have ranged from 0.003 to 63 years. New scenarios developed for the current study represent 100-ft TOTs that range from about 10 to 1083 years. Based on data generated in G&M's aquifer survey, these new scenarios represent underdeveloped aquifers in arid regions associated with low recharge settings, or what is more likely, low-permeability non-aquifers in all climatic settings.

Within the constraints of this project, low-velocity hydrogeologic settings had to be conceptualized as being composed of one or two layers of homogenous, isotropic porous media. Real-world complexities such as natural variations in layer geometry and permeability were not simulated. The processes of flow and transport within an unsaturated zone were also not simulated.

Our modeling effort is further limited by significant assumptions concerning the source of contamination. Sources behave in simple predictable ways, and do not alter the assumed natural rate of ground-water flow through the model flow fields. Moreover, sources are small with simple geometries, and do not create the magnitude of mass loadings that could be simulated for large areal sources.

The models used in this study are limited in representing all complexities that can be observed on real sites. However, they are very useful in a comparative analysis which has the objective of identifying general and fundamental relationships between velocity/TOT and concentrations/risks.

There are two primary objectives to G&M's scope of work. The first objective was to develop new scenarios and provide ICF with model output that would be used in the liner-location model (or some derivative of that model) that would provide numerical estimates of health risks to a hypothetical exposed population. The second objective was to establish the general relationships between TOT and concentration of contaminants observed at a specified distance downgradient. The specified distance was set at an arbritary 100-ft length measured along a centrally located flow line orignating from the source of contamination and terminating at a monitor well. Because the ground-water velocity (not the contaminant velocity) is the key model variable that controls TOT, the relationship between velocity and concentration is equally important and was studied.

CONCLUSIONS

Liner-location model runs by G&M indicate a very wide range of concentrations resulting from six ground-water contaminants emanating from two contaminant sources located within six hydrogeologic settings. Based on Random-Walk transport model simulations, the following conclusions can be drawn concerning TOT/ ground-water velocities and peak contaminant concentrations:

1. Peak concentrations decrease with increasing TOTs (with decreasing ground-water velocities) when the contaminant mass input is rate-limited by the underlying ground-water flow field, all other parameters held equal.

2. Peak concentrations increase with increasing TOTs (with decreasing ground-water velocities) when mass input at the source and all other model parameters are held equal.

3. A low-velocity, near-surface layer can significantly increase the TOT from a facility to any given distance in an underlying uppermost aquifer and also decrease peak concentrations in the same.

METHODOLOGY

The technical approach used by G&M to meet the project objectives proceeded through the following four steps:

- Developed new model scenarios with input from LDB
- Examined the existing liner-location models to see if they were suitable in present form for application to the new scenarios
- Made model changes, performed the simulations, and delivered output to ICF for their risk estimates
- Analyzed the output from the Random-Walk model and identified basic relationships between TOT/ground-water velocity and peak contaminant concentrations and breakthrough times.

Scenario Development

Scenarios are identified in this project by the same characteristics that were used in the previous liner-location project. A mass transport model scenario is identified on the basis of three characteristics -- a generic ground-water flow field, a contaminant mobility class, and a distance to an exposure point.

The flow field is conceptualized as a two-dimensional vertical plane extending beneath the contaminant source to a depth that represents the base of shallow ground-water circulation beneath the site. Unlike the flow systems of the liner location project, the unsaturated zone is eliminated in the current analyses. The velocity field within the generic flow system was not simulated, nor was it based on a national survey as was done with the liner-location project. Rather, a range of velocities and dimensions were arbitrarily assigned to the generic settings in order to bracket the TOT criteria currently under consideration by LDB.

Figure 1 shows the conceptual orientation of a flow field with respect to a source area and a generic exposure point developed in the liner-location project. Figure 2 shows the nine generic flow fields used in the liner-location project; these were developed from a survey of 67

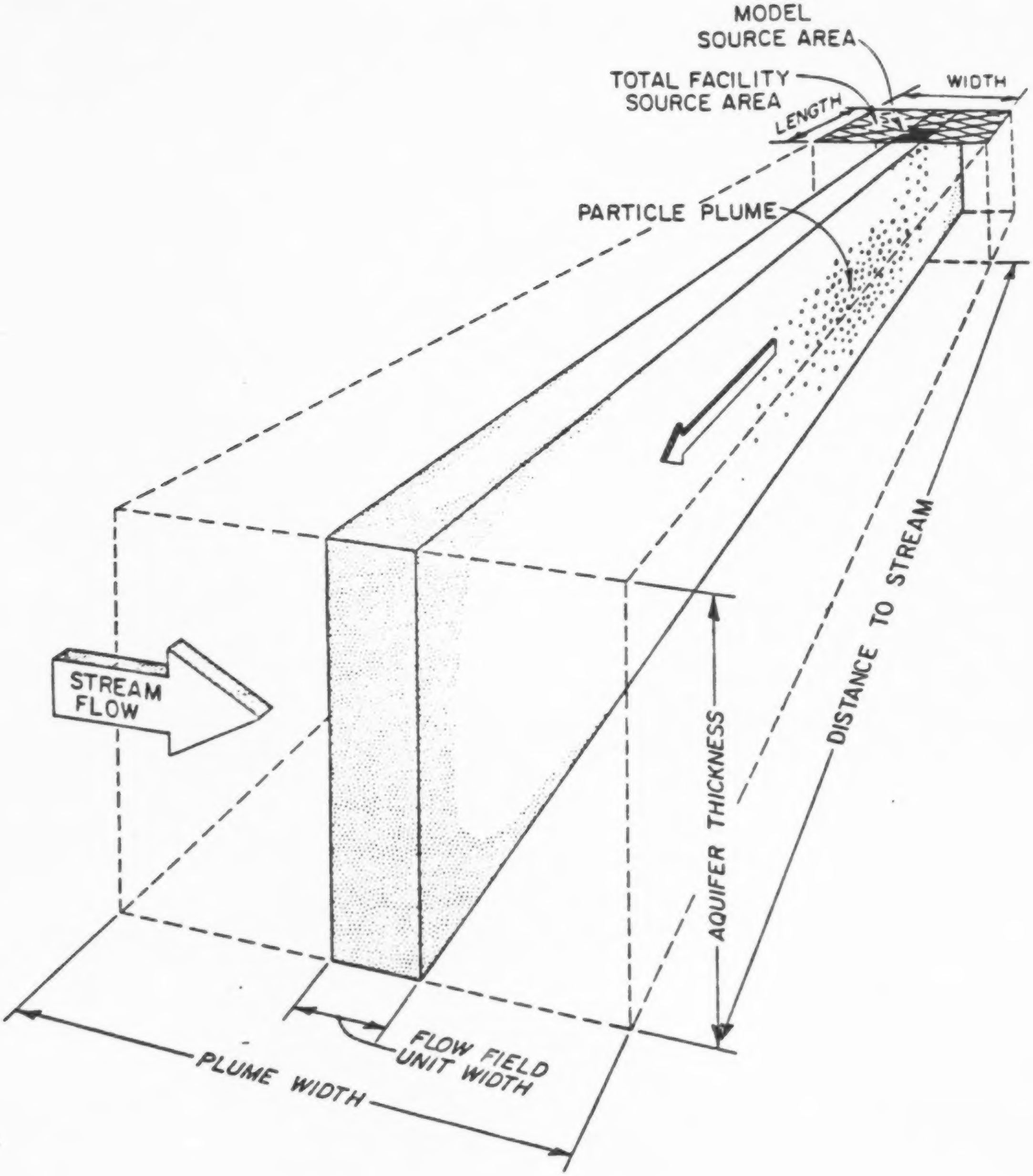
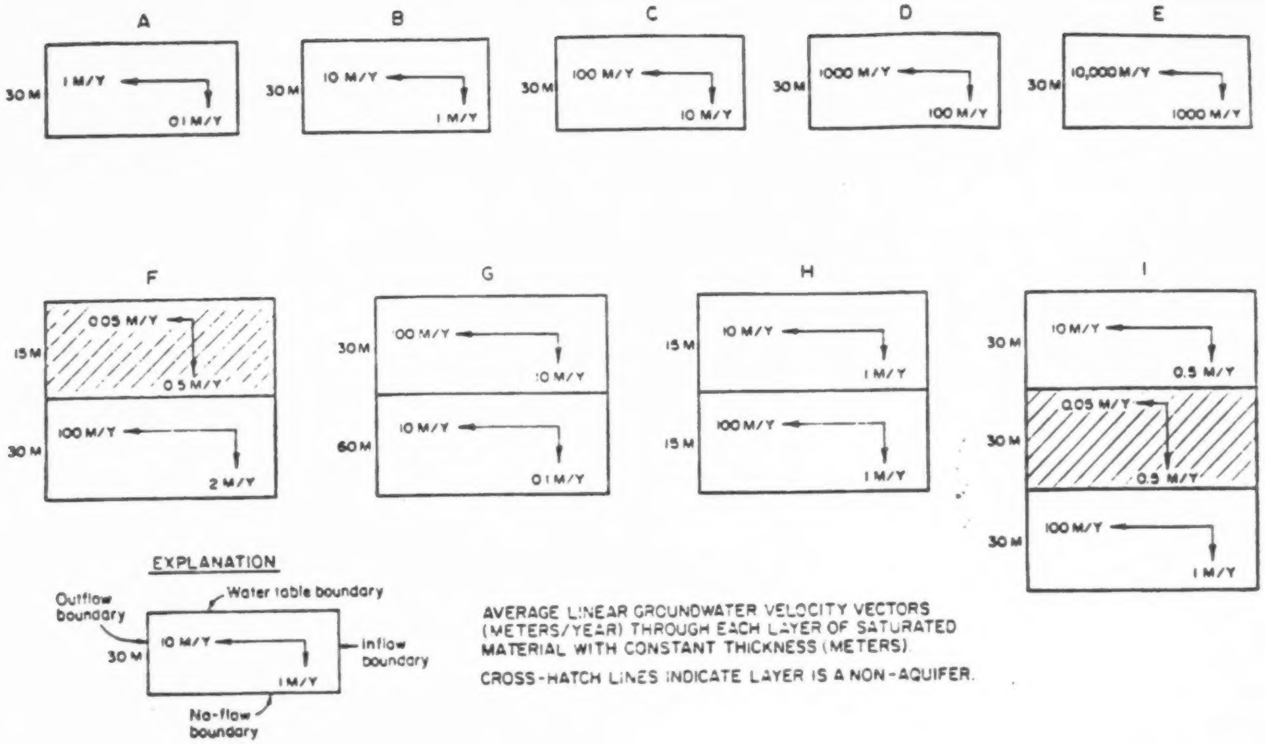

MODEL SOURCE AREA
TOTAL FACILITY SOURCE AREA
LENGTH
WIDTH
PARTICLE PLUME
STREAM FLOW
AQUIFER THICKNESS
DISTANCE TO STREAM
FLOW FIELD UNIT WIDTH
PLUME WIDTH

Figure 1. Orientation of a Generic Flow Field with Respect to the Contaminant Source and the Surface Water Outflow Boundary (from Geraghty & Miller, 1984).



A
30 M
1 M/Y
0.1 M/Y
B
30 M
10 M/Y
1 M/Y
C
30 M
100 M/Y
10 M/Y
D
30 M
1000 M/Y
100 M/Y
E
30 M
10,000 M/Y
1000 M/Y
F
15 M
0.05 M/Y
0.5 M/Y
30 M
100 M/Y
2 M/Y
G
30 M
100 M/Y
10 M/Y
60 M
10 M/Y
0.1 M/Y
H
15 M
10 M/Y
1 M/Y
15 M
100 M/Y
1 M/Y
I
30 M
10 M/Y
0.5 M/Y
30 M
0.05 M/Y
0.5 M/Y
30 M
100 M/Y
1 M/Y
EXPLANATION
Outflow boundary
Water table boundary
30 M
10 M/Y
1 M/Y
Inflow boundary
No-flow boundary
AVERAGE LINEAR GROUNDWATER VELOCITY VECTORS (METERS/YEAR) THROUGH EACH LAYER OF SATURATED MATERIAL WITH CONSTANT THICKNESS (METERS).
CROSS-HATCH LINES INDICATE LAYER IS A NON-AQUIFER.

Figure 2. Nine Generic Ground Water Flow Fields Used in the Liner-Location Transport Model Scenarios.

case studies of regional water-supply aquifers in all major ground-water regions of the U.S. (as defined by the U.S. Geological Survey; McGuiness, 1963). Although useful for studying risks of ground-water exposure from contaminated aquifers, the generic settings in Figure 2 all have TOT values to 100-ft distances that are less than 100 years.

Figure 3 shows six additional generic flow fields developed for the current study. Two generic flow fields shown in Figure 3 were developed to provide a way of testing risks at the TOT values that are equal to the proposed criteria of 100 years for landfills and disposal surface impoundments, and 10 years for storage surface impoundments and waste piles (flow fields K, L, respectively). Four other new flow fields were created to provide concentration and risk estimates for TOT values that were larger than these (flow fields J, M, N, and O).

Three ground-water contaminants from each of two mobility classes were selected by GCA for the current analysis. In Mobility Class 1, defined by a retardation factor (Rd) equal to 1.3, acrylonitrile, phenol, and chromium VI were selected. In Mobility Class 2, having a Rd equal to 32, GCA selected benzene, xylene, and nickel.

The six generic flow fields and two mobility classes combine to make 12 mass transport model scenarios for simulation. Table 1 shows additional model parameters that were used for these scenarios. Contaminant velocities were calculated with the ground-water velocities shown in Figure 3 and the two Rd factors discussed above. Dispersivities are estimated on the basis of literature values and work performed in the liner-location project, allowing for some adjustment of low velocity, diffusion-controlled movement to be discussed later. Effective porosities are also based on work done in the liner-location project (Geraghty & Miller, 1984). As shown in Table 1, "Layer 1" refers to the single layer of flow fields J, K, and L, or the upper layers of flow fields M, N, and O. This layer is consistently equal to 20-ft thick in the single layer classes and 10-ft thick in the double layer classes. Layer 2, the underlying layer in flow fields M, N, and O, is consistently set to 20-ft thick.

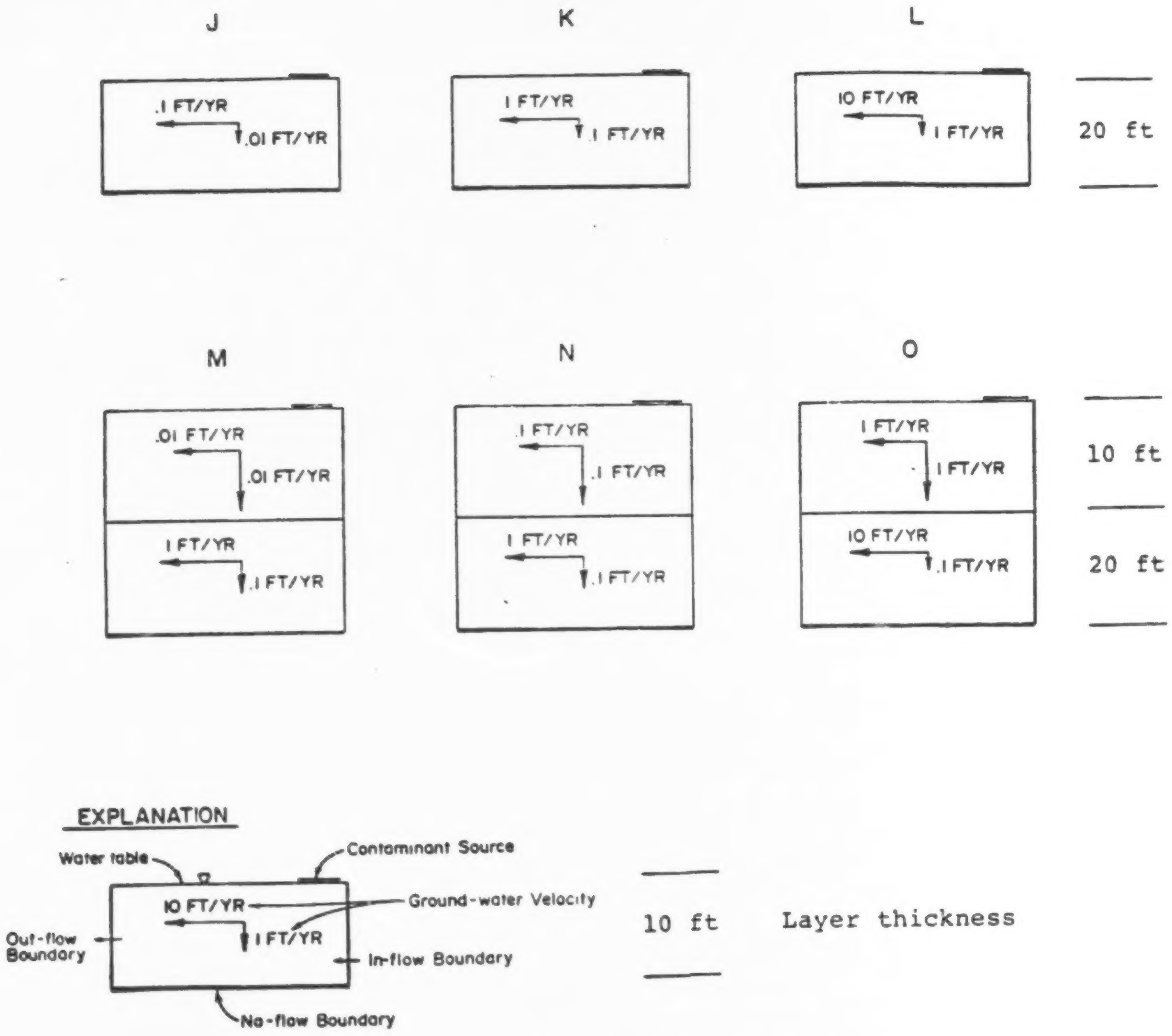

J
.1 FT/YR
.01 FT/YR
K
1 FT/YR
.1 FT/YR
L
10 FT/YR
1 FT/YR
20 ft
M
.01 FT/YR
.01 FT/YR
1 FT/YR
.1 FT/YR
N
.1 FT/YR
.1 FT/YR
1 FT/YR
.1 FT/YR
O
1 FT/YR
1 FT/YR
10 FT/YR
.1 FT/YR
10 ft
20 ft
EXPLANATION
Water table
Contaminant Source
10 FT/YR
1 FT/YR
Ground-water Velocity
Out-flow Boundary
In-flow Boundary
No-flow Boundary
10 ft
Layer thickness

Figure 3. Six Generic Flow Fields Used to Study the Time-of-Travel Criteria.

TABLE 1.
CONTAMINANT VELOCITIES, DISPERSIVITIES, AND EFFECTIVE POROSITIES FOR TWELVE TRANSPORT MODEL SCENARIOS

Scenario Identification Number[a]	Horizontal Contaminant Velocity		Dispersivity				Effective Porosity	
	Layer 1 (ft/yr)	Layer 2 (ft/yr)	Layer 1		Layer 2		Layer 1 (percent)	Layer 2 (percent)
			Long.[b] (ft)	Trans.[c] (ft)	Long. (ft)	Trans. (ft)		
J-1-100	7.7×10^{-2}	—	6.6	6.6	—	—	10	—
J-2-100	3.1×10^{-3}	—	6.6	6.6	—	—	10	—
K-1-100	7.7×10^{-1}	—	6.6	6.6	—	—	20	—
K-2-100	3.1×10^{-2}	—	6.6	6.6	—	—	20	—
L-1-100	7.7	—	6.6	6.6	—	—	20	—
L-2-100	3.1×10^{-1}	—	6.6	6.6	—	—	20	—
M-1-100	7.7×10^{-3}	7.7×10^{-1}	1.0	.70	6.6	.66	5	20
M-2-100	3.1×10^{-4}	3.1×10^{-2}	1.0	.70	6.6	.66	5	20
N-1-100	7.7×10^{-2}	7.7×10^{-1}	.33	.13	6.6	.66	10	20
N-2-100	3.1×10^{-3}	3.1×10^{-2}	.33	.13	6.6	.66	10	20
O-1-100	7.7×10^{-1}	7.7	6.6	.66	6.6	.66	20	20
O-2-100	3.1×10^{-2}	3.1×10^{-1}	6.6	.66	6.6	.66	20	20

[a] Identification number = flow field - mobility class - exposure point distance, in feet

[b] Long. = Longitudinal dispersivity, in direction that is parallel to ground-water flow

Trans. = Transverse dispersivity, in direction that is orthogonal to ground-water flow

To maintain some consistency for comparison with the liner-location model runs, the source term is treated as a line-source positioned at the upgradient end of the flow field (Figure 3). The source is arbitarily set at 32.8 ft (10m) long and one ft wide. In the Random-Walk model runs, a standard mass input of one kilogram (Kg) (represented by 1,000 particles) is input over a 1-year time step. Breakthrough of the one Kg mass of contaminants is tracked through the flow fields to the hypothetical exposure well which fully penetrates the layer of interest (the higher velocity layer in two-layer flow fields).

Random-Walk Model Development

Because of several significant differences between the previous and current application of the mass transport and liner-location models, both G&M and ICF were required to further develop the models before they could be run. The following discussion will focus on those changes that were made in G&M's particle tracking code which utilizes the Random-Walk model of Prickett, Naymik, and Lonnquist (1981).

Minor code changes were required because of the low velocity generic flow fields and because the source terms are handled differently from the liner-location application. More specifically, the changes were made in order to handle the following factors:

- Longer simulation times
- Shorter exposure distances
- Slower ground-water velocities
- Generic flow field-limited mass loading
- Changes in scaling factors.

Longer simulation times and short exposure distances were handled with trivial changes and require no further discussion here. The effects of slower velocity on the dispersion term and changes in the scaling factors applied by ICF were non-trivial and are discussed below.

Velocity and Dispersion

The spreading of contaminants through subsurface materials is caused both by mechanical dispersion and molecular diffusion. Under most aquifer conditions, where ground-water velocities are greater than one foot per year, the molecular diffusion component can be ignored. Such was the case in the previous application for the liner-location project. At very low velocities, such as those seen in Figure 3 for flow field M, mechanical dispersion is negligable relative to molecular diffusion and this must be accounted for in the mathematical model (Freeze and Cherry, 1979).

Because the Random-Walk model generally assumes that diffusion is negligable, and relies on only a dispersivity term, it was necessary to define a new term called "effective dispersivity" defined as follows:

$$\alpha_e = \frac{\alpha V + D^*}{V}$$

where:

α_e = Effective dispersivity (L)

α = Longitudinal (or tranverse) dispersivity, (L)

V = Average linear ground-water velocity (L/T)

D^* = Diffusion coefficient, (L^2/T)

In the current scenario simulations, only flow field M was significantly affected by the diffusion coefficient. Values of dispersivity listed in Table 1 include the diffusion term.

Source Term

In the previous liner-location project, a separate submodel developed by Pope Reid Associates was used to simulate the stochastic process of facility failure and mass release of contaminants from a hypothetical facility.

Release rates from the Pope Reid model were generally small enough so that the project team could ignore hydraulic changes in the underlying generic flow fields. It was assumed that leachate drained freely from the liner system and, while delayed by passing through the unsaturated zone, the leachate release rate was not limited by underlying earth materials or by low ground-water velocities. This methodology was considered acceptable since generic flow fields A through I (Figure 2) had relatively large values of velocity.

ICF's original liner-location model reads the standard breakthrough concentrations from G&M's model output and scales the data according to the size of the facility. It then creates future scenarios by adding the adjusted standard concentration curves in a sequence determined by the failure and leakage history of the Pope Reid model. ICF modified this code to by pass the Pope Reid simulation and assume a more simplified life expectancy of the source term. They also deleted the scaling factor for the facility size and added a new term to handle dispersivity in the third dimension oriented at right angles to the vertical flow fields.

In the current application by ICF, the Pope Reid model was replaced with an assumption that the underlying hydrogeologic materials would have a control on the volumetric release rate of leachate from the source. Time and resources did not permit simulating this rigorously under a set of hydraulic parameters and boundary conditions. Rather, we assumed that the vertical leakage rate from the source was equal to the vertical seepage velocity within the underlying flow field.

Table 2 lists for each of the six flow fields the critical source term characteristics that affect the leachate release rate from the 32.8 ft^2 area. As shown, we assumed a contamination concentration of 100,000 mg/l in the leachate in order to show how the mass load can range over three orders of magnitude (from .045 to 18 kg/yr). This high concentration is slightly larger than the most soluable species considered, phenol (with solubility of 93,000 mg/l), and therefore the mass loading rates represent a conservative upper-bound estimate.

To meet G&M's project objectives, it was necessary to evaluate the effects of both the standard and flow field-adjusted mass load source strengths. The interpretation

TABLE 2.
SOURCE-TERM CHARACTERISTICS FOR SIX GENERIC FLOW FIELDS

Flow Field	Vertical Ground-Water Velocity (ft/yr)	Effective Porosity (percent)	Recharge Per Unit Area (ft/yr)	Leachate Release Rate[a] (ft^3/yr)	Mass Loading[b] (kg/yr)
J	.01	10	.001	.033	.092
K	.1	20	.020	.656	1.8
L	1.	20	.200	6.560	18.
M	.01	5	.0005	.016	.045
N	.1	10	.010	.328	.92
O	1.	20	.200	6.560	18.

[a] Release rate is the flow field-controlled volumetric discharge of leachate over a strip source area with dimensions of 1 ft x 32.8 ft.

[b] Hypothetical examples assuming a contaminant concentration of 100,000 mg/l in the leachate.

of these two conditions deserves some discussion. The standard mass input to all flow field scenarios can be conceptualized as one of the following:

- The facility is engineered and fails in a consistent way that creates an equal release of mass that is input directly to the saturated zone of each flow field.
- An unsaturated zone serves to spread, dilute, attenuate, etc. releases of different magnitudes and thereby converts them all to equal inputs to the saturated zone.

The flow field-controlled, adjusted mass input can be conceptualized as follows:

- The facility is engineered and fails in a variety of ways, however, a low rate of flux through the cover materials or a low permeability of host materials controls the actual release of mass and the subsequent direct input to the saturated zone.
- An unsaturated zone serves to convert releases of equal magnitude to inputs of variable magnitude that are controlled by the low-flux, low-permeability setting.

In G&M's opinion, the flow field-controlled situations will be more common in low-velocity settings.

The source life for the landfill strip was calculated by assuming an initial total mass and storage per unit area and calculates the time to deplete the mass through leaching. Based on mail survey data studied by ICF in the liner-location project, G&M and ICF assumed an average contaminant density in landfilled wastes of 0.30 kg/ft^3. The average thickness of landfilled waste was assumed to be 20 feet, thereby creating a mass storage per unit area of 6 kg/ft^2. The leaching rate was set equal to the product of the seepage velocity of the underlying flow field, the area of the source, and the concentration of the particular chemical constituent. The life of the storage surface impoundment source was assumed to be 30 years. Mass release was assumed to be the product of seepage velocity of the underlying flow field, area of the source, and concentrations assumed for the particular contaminant.

The standard breakthrough curve generated from a 1-kg input of contaminant mass at the source is adjusted to fit the particular mass loading conditions for each contaminant. Figure 4 shows how the amplitude of the breakthrough curve can be adjusted upward to simulate a loading rate of 1.8 kg/yr, corresponding to a leachate with a contaminant concentration of 100,000 mg/l for flow field K (Table 2).

Figure 4 also shows the effect of biodegradation on concentrations of the standard breakthrough curve. The example shown is for a species that was loaded at the standard rate of 1 kg/yr but has biodegraded with a half-life of 20,000 days. As shown, the peak concentration is not only smaller but occurs earlier in time. For most of the small velocity scenarios considered in our study, a relatively slow rate of biodegradation could yield significant reductions in concentration at hypothetical exposure points. Unfortunately, time and resources did not permit establishing a half-life for the organic species which are known to biodegrade, especially benzene and acrylonitrile. The estimates of concentrations are, therefore, conservatively large for these species.

Transverse Dispersion

One of the limitations of the earlier application of the Random-Walk model is that dispersion of contaminants was limited to the vertical plane and transverse dispersion at right angles to the plane was not simulated. Because the exposure points are centrally located along an axis that divides the source area into two equal parts, this does not lead to major errors with large areal sources (simulated in the liner-location project). For the current application, however, it is necessary to consider dispersion in the third direction.

A correction factor was determined empirically. This was accomplished by comparing several analytical solutions to the Random-Walk model output. The solutions for an instantaneous mass input at a point source for one- and two-dimensional cases (Hunt, 1978) are used for this purpose. The one-dimensional equation can be converted to a quasi two-dimensional solution by dividing the concentration by the thickness of the aquifer in question. Figure 5 illustrates how, for scenario K-1-100, the 1-D solution adjusted by thickness is a very close match to the Random-Walk output (scatter of points). The two-dimensional equation can similarly be converted to quasi three-dimensional

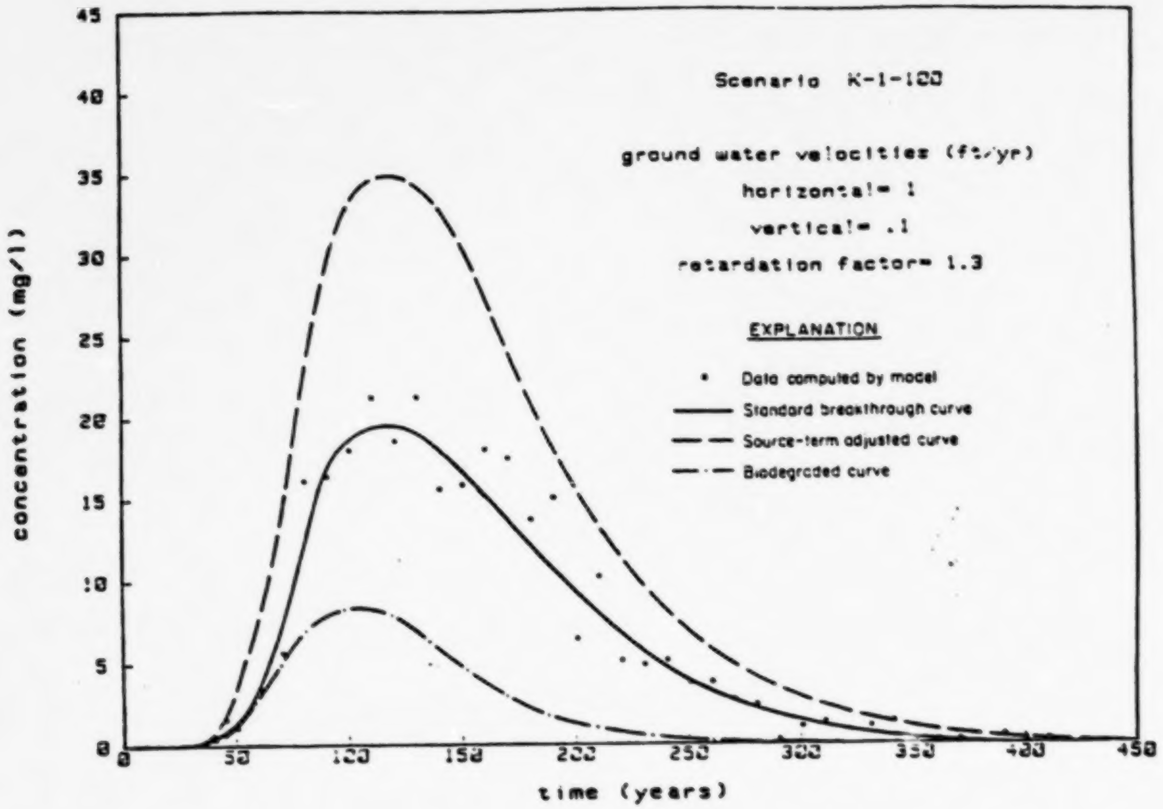


Figure 4. Examples of Standard Breakthrough Curve and How It May be Adjusted to Simulate Layer Mass Inputs and-Biodegradation.

by dividing by thickness. Figure 5 illustrates the breakthrough curve for the 2-D solution adjusted for vertical thickness, which has a concentration that is small than the quasi two-dimensional solution by a factor that ranges from about 1/8 to 1/15. This relationship of concentrations for the 1-D and 2-D cases appears to hold for other velocity fields considered in our analyses. For this reason, and because risks are being examined at the order-of-magnitude level, G&M advised ICF to adjust the Random-Walk model standard curves downward by a factor of 1/10 to account for dispersion in the third dimension.

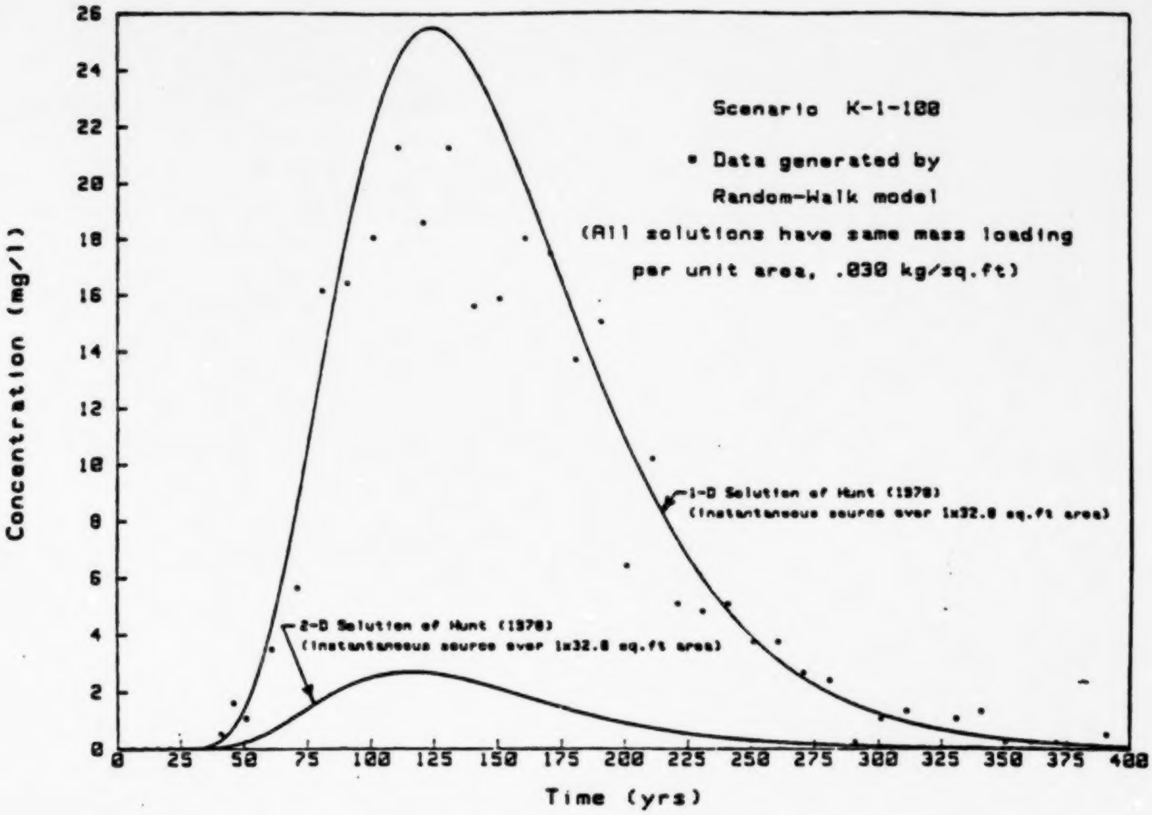


Figure 5. Comparison of Random-Walk Model Output With Two Analytical Solutions.

RESULTS

Appendix A includes tables of output produced by the Random-Walk model which show concentration vs. time resulting from a standard 1-Kg mass input for 12 scenarios. Mass loading to a surface stream is included for each scenario as a check on the concentration breakthrough. Appendix B presents the same output in graphical format and includes the best fit curve to the scatter of data which is typical of particle tracking code output.

Random-Walk Output

Table 3 shows the critical times and peak concentrations of the standard breakthrough curves and for breakthrough curves resulting from an adjusted, flow field-controlled mass release (Table 2). Table 3 also shows for each of the 12 scenarios, the TOT to the 100-ft exposure point. Under the proposed TOT criteria, flow fields L and O constitute vulnerable conditions for landfills and disposal impoundments. All flow fields would meet the TOT criteria for non-vulnerable conditions for storage impoundments and waste piles.

The adjusted load breakthrough curves represent data used by ICF in their simulations of future concentrations. It is important to note that the critical time of starting, ending, and peaking of the curves are not adjusted, only the magnitude of the concentration is adjusted.

General observations based on the one-yr mass input to the flow fields should hold true for other transient cases involving longer simulation times. If time is considered to be a relevant measure of risk, scenarios involving the lowest velocities and least mobil constituents must be associated with the lowest risks. If concentration is the major control on risk, Table 3 suggests that the hydrogeologic setting/mobility combination, which is best suited for reducing risks, is also sensivitive to the strength of the source term.

Liner-Location Model Output

The original liner-location model developed by ICF simulates a concentration and corresponding risk profile over a 400-year simulation period. Individual risks are computed on the assumption of a 70-year lifetime with a dose

TABLE 3.
CRITICAL TIMES AND PEAK CONCENTRATIONS OF BREAKTHROUGH CURVES AND 100-FT TOT'S FOR TWELVE SCENARIOS

Scenario Identification	Critical Times			Peak Concentrations		Time of Travel
	Start (yr)	End (yr)	Peak Time (yr)	Standard Load[a] (mg/l)	Adjusted Load[b] (mg/l)	To 100-ft (yr)
J-1-100	300	5,000	1,250	42.4	3.9	1000
J-2-100	8,000	110,000	32,270	1.80	.17	1000
K-1-100	35	450	115	19.5	35.	100
K-2-100	800	11,000	3,000	.92	1.7	100
L-1-100	4	53	12	20.5	370.	10
L-2-100	80	1,100	320	.87	16.	10
M-1-100	250	120,000	1,360	1.2	.054	1083
M-2-100	8,000	360,000	33,000	.048	.0022	1083
N-1-100	120	800	260	14.7	4.8	186
N-2-100	3,000	20,000	6,440	.63	.21	186
O-1-100	5	120	21.5	9.9	65.	18.6
O-2-100	150	3,500	550	.45	2.9	18.6

[a] Standard mass load of one kilogram for one year over the strip source area (32.8 ft^2)

[b] Standard mass load adjusted by flow field-controlled leachate relase rates (Table 2).

based on a running average concentration over any 70-year period. In the current study, simulation times were much longer than 400 years and it seemed reasonable to compute concentrations at greater intervals, assuming that the point of concentration represents a 70-year average.

In this study, concentrations and risks are provided by G&M and ICF, respectively, for landfills and surface impoundment sources at the following time intervals: 50, 100, 200, 500, and 1,000 years and at steady state. Although the calculated source life of both source types is limited to several thousand years, it was necessary in some cases to extend this in order to reach the hypothetical steady-state case. The project team composed of G&M, GCA, and LDB personnel agreed that the time factor begins to take on more importance than concentrations beyond 1,000 years, and no additional time steps between 1,000 years and the hypothetical steady-state case are calculated.

Concentrations and risks vary over many orders-of-magnitude and represent a total of 72 separate scenarios (2 source strength terms x 2 source types x 6 contaminants x 6 flow fields x 6 time intervals). GCA Corporation will discuss the significance of these with respect to the TOT criteria.

Relationship of TOT and Velocity to Peak Concentrations

The relationships of TOT and velocity to peak concentrations are highly depended on the source term. This is because the advection-dispersion-retardation models (both analytical, numerical and particle tracking) require that the concentration at any downgradient location is directly proportional to both contaminant concentration and volumetric release rate of leachate at the source. Because the assumption of the concentration of contaminants at the source being equal to the saturated concentration (in pure water) is considered highly conservative, an additional set of runs were created where the mass in storage and contaminant concentration in the leachate is reduced by a factor of ten. This yields a 10-fold decrease in concentrations for all 72 scenarios.

Changing the concentration at the source impacts peak concentrations but is completely independent of TOT and velocity. The other half of the source term, the volumetric leachate release rate can be related to TOT and velocity.

For the somewhat limited instances where mass loading is independent of the setting (i.e., the same for each scenario), two relationships are observed. First, in single-layer flow systems, the concentration tends to decline with increasing velocity to a certain point, beyond which the concentration becomes essentially steady and the potential exposure time decreases with increased velocity. Second, when a lower velocity layer is positioned above the aquifer of interest (compare settings M and N to K; and compare O to L), peak concentrations are reduced because of the slow, controlled release of contaminants to the underlying layer in which the hypothetical well is screened.

For the more prevalent situations where the mass input is allowed to be controlled by the hydrogeologic setting and the adjusted leachate release rates prevail, the relationship of velocity to concentration changes somewhat. In single-layer cases, peak concentrations increase in direct proportion to increased horizontal velocities. If low velocity layers are positioned above higher velocity layers, peak concentrations within the latter are reduced, as they are with the standard load input.

Figures 6 and 7 show the general relationships between peak concentrations and TOTs for the standard and adjusted mass load input scenarios. Figure 6 shows that peak concentrations generally increase with increasing TOT. A noteworthy exception to this relationship is apparent for scenarios involving flow field M. The order-of-magnitude decrease in peak concentration for scenarios M-1 and M-2 is attributed to diffusion-controlled transport in the upper layer and to the two order-of-magnitude contrasts in velocity between the upper and lower layers of the flow field. When these conditions prevail, peak concentrations become less sensitive to the mass loading rate.

Figure 7 shows a more consistent relationship where peak concentrations decline with increasing TOT values. The change in slope of the line between scenarios O and N to scenarios involving flow field M is attributed to the same characteristics identified above. Apparently, flow field M has a distinct advantage for minimizing contaminant concentrations in an underlying velocity layer. This observation is consistent with previous work done for the liner-location project in which it was shown that the effect of adding low velocity layers above the aquifer of interest is to greatly reduce peak concentrations and spread out the breakthrough curve over longer periods of time.

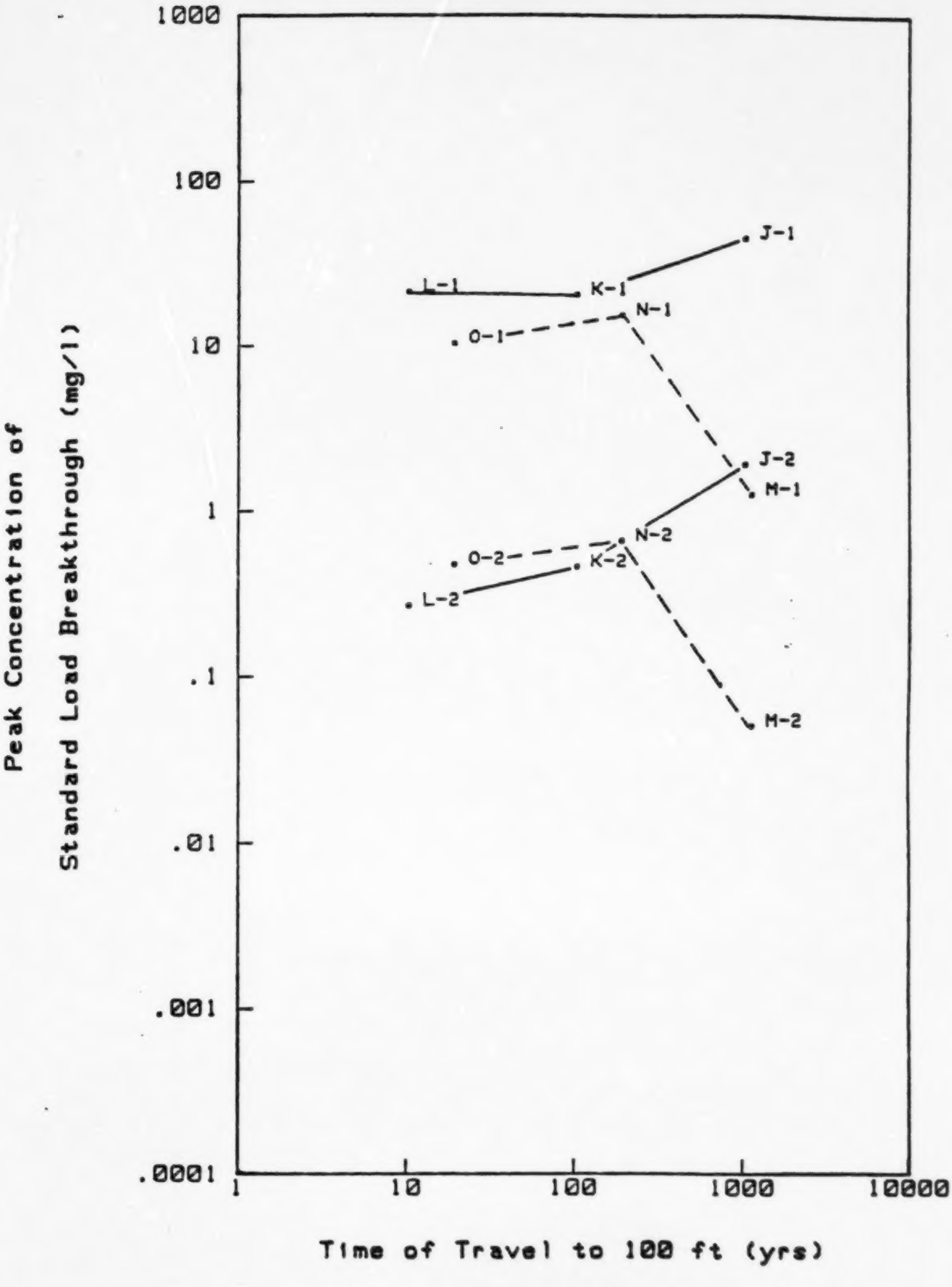


Figure 6. Plot of Contaminant Concentrations vs. 100-ft TOT for Standard Mass Load Input Scenarios.

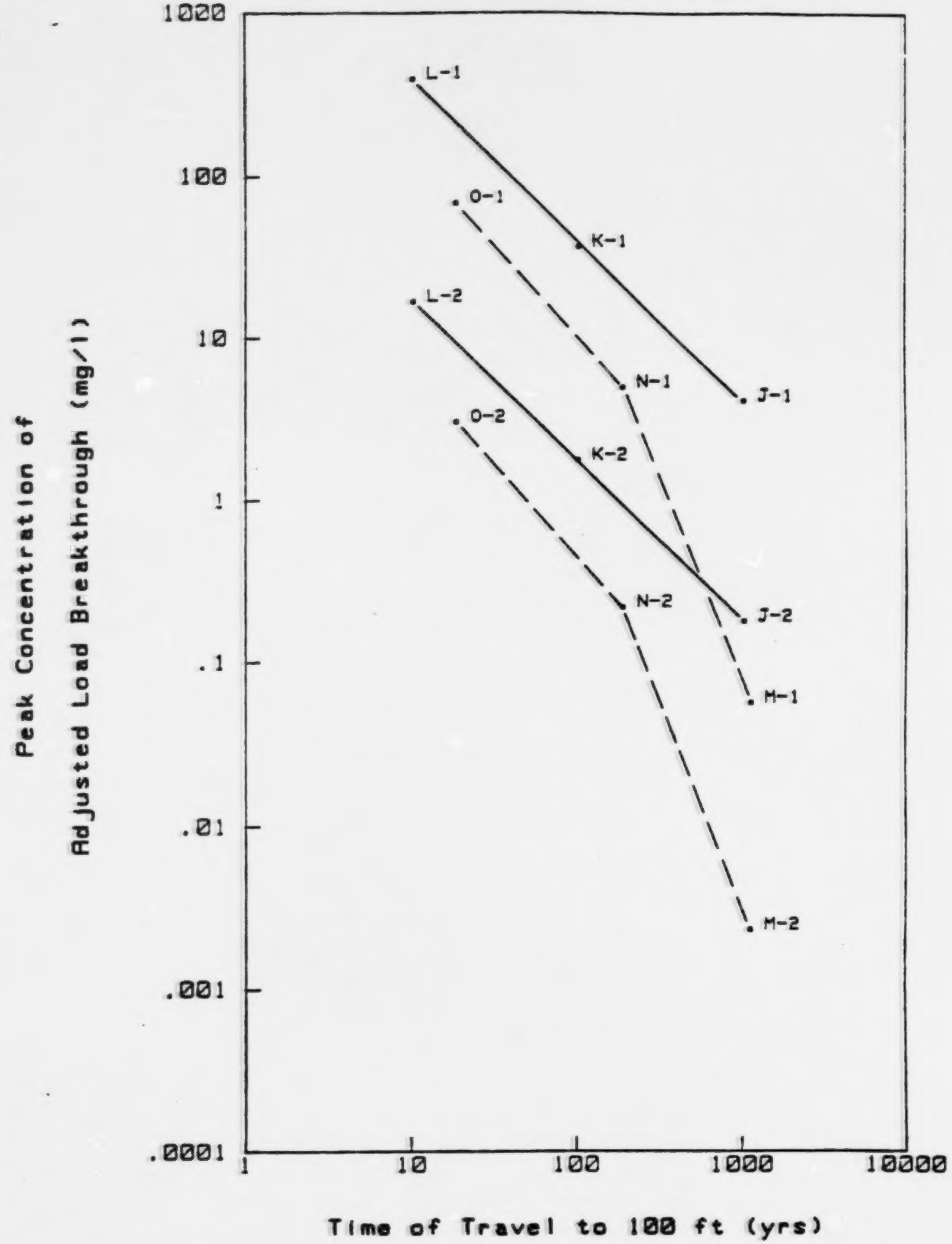


Figure 7. Plot of Peak Contaminant Concentration vs. 100-ft. TOT for Adjusted Load (Flow Field-Controlled) Input Scenarios.

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The apparent reversal of relationships between TOT/velocity and concentrations is largely a function of the source term in the model. It also raises an issue concerning to what degree low-velocity flow fields will actually limit mass loadings from facilities located in these settings. However, it is clear that the lowest concentrations are associated with settings that involve very low velocity surficial layers (with diffusion-controlled transport) overlying an aquifer that, by itself, would not have an acceptable velocity to meet current TOT criteria.

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